QE
125
A12
5

Library of

Wellesley College.

Presented by Michigan Geological Survey

No 49493

GEOLOGICAL SURVEY OF MICHIGAN.
MAP OF THE
IRON AND COPPER REGIONS
OF
NORTHERN MICHIGAN
Showing RANGES And TOWNSHIPS.
Compiled from map published with Vol. I. of the Reports of the
GEOLOGICAL SURVEY OF MICHIGAN.
SCALE,
1894.
Division of Township.
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
LONGITUDE WEST FROM WASHINGTON.
RANGES WEST.
TOWNSHIPS NORTH.
LAKE SUPERIOR
WISCONSIN.
GREEN BAY
KEWEENAW BAY
Standards Rock
Traverse Id.
Huron Ids.
Granite Id.
Middle Id.
L. Vieux Desert.
Brule L.
L. Antoine
Michigamme L.
Torch Lake.
Portage Lake.
Paint River.
Menominee River.
Middle Branch
West Branch
Dead River
Carp River
Escanaba River
Ford River
Chocolate River
Teal L.
Goose L.
Otter L.
Gratiot L.
Schlatters L.
Little Montreal River.
Copper Harbor.
L'ANSE.
CALUMET
HANCOCK
HOUGHTON
REPUBLIC
MICHIGAMME
MENOMINEE.

GEOLOGICAL SURVEY OF MICHIGAN

LUCIUS L. HUBBARD, STATE GEOLOGIST

UPPER PENINSULA

1881-1884

LOWER PENINSULA

1885-1893

VOL. V

PART I. UPPER PENINSULA: IRON AND COPPER REGIONS

PART II. LOWER PENINSULA: DEEP BORINGS

PUBLISHED BY AUTHORITY OF THE LAWS OF

MICHIGAN

UNDER THE DIRECTION OF

THE BOARD OF GEOLOGICAL SURVEY

LANSING

ROBERT SMITH & CO., STATE PRINTERS AND BINDERS

1895

Entered according to Act of Congress, in the year 1895, by

GOVERNOR JOHN T. RICH,

for the State of Michigan, in the Office of the Librarian of Congress, Washington.

GEOLOGY LIBRARY
QE
125
A12
(5)

PREFATORY HISTORICAL NOTE.

The last published report of the Michigan Geological Survey, in the series of which the following pages constitute Volume V, was written by Dr. Carl Rominger, at that time State Geologist, and was published in 1882. It described work done and observations made by Dr. Rominger in the iron region of the upper peninsula, west and south of Marquette.

The first part of the present volume, also written by Dr. Rominger, beside covering work done in the iron region in 1881 and 1882, also includes observations made in the copper region in the following year or years. The manuscript of this report was in the possession of the Board of Geological Survey at the time when Dr. Rominger's successor, the late Charles E. Wright, was appointed State Geologist, in May, 1885.*

Accompanying this report is a small map of the western part of the upper peninsula, copied from a map published with Vol. I of the series. Although defective in several minor details, which could not well be corrected without making an entirely new map, from independent data, it will serve the purpose for which it is intended, to help the reader orient himself in connection with the descriptions in the text.

The second part of the present volume is a paper by Dr. A. C. Lane, on deep borings in the lower peninsula, and is based on work done by the late Mr. Wright. As stated in my letter of transmittal, this paper was practically completed during the

*Referring to the first part of this report, Dr. Rominger, in 1883, said: "The description of all the results obtained comprises the space of about fifty or sixty printed pages, too small for a separate publication in book form. I respectfully suggest, therefore, to wait with it until the results of another year's work can be added and a volume can be printed corresponding with the previous four volumes." The long delay in the publication of said report has, doubtless, been caused by the feeling which gave rise to Dr. Rominger's request—that the complete report by itself was not large enough to fill a volume. The smallest of the preceding volumes of the same series was of 262 pages, while the largest was of 581 pages.

See Dr. Rominger's report for 1882-83, in report of the State Board of Geological Survey, 1893.

administration of my immediate predecessor, Dr. M. E. Wadsworth, and in its original form was sent to the Board of Geological Survey in 1892. It has since been revised and somewhat enlarged, and is preceded by a brief chapter on the origin of salt, gypsum, and petroleum. The printing of this volume was begun in November, 1893. The reproduction of the plates that accompany it, although begun a month earlier, was not completed until November, 1894.

Charles E. Wright was State Geologist from May, 1885, to the time of his death, in March, 1888. In May of the latter year Dr. Wadsworth succeeded Mr. Wright, and continued to hold the office until May, 1893. During Dr. Wadsworth's administration the Survey had its headquarters in the Mining School building, at Houghton, where its corps had the exclusive use of a room, and unrestricted access to all departments of the school. Up to that time, except possibly during the terms of Dr. Alexander Winchell, the Survey had no habitation other than the private offices or houses of the respective State Geologists. To this want of permanent quarters is doubtless due the fact, that, in times past the collections of the Survey and much of its property have been dispersed or lost.

In the absence of a suite of rock samples that illustrate the geological formations of the State, many of them its economic products, each incoming State Geologist must collect anew, and, in the absence of records and field notes, must inform himself by personal inspection in the field, or through his assistants, what are the relations of the rocks and their geological significance. In a territory like that of northern Michigan, vast, in many places difficult of access, and of a complex geological structure, the acquisition of this knowledge must and does take a number of years, especially when we consider the shortness of the field season, and the limited means applicable to the work. In view of these facts, it should not be a matter of surprise that the resignation of one State Geologist and the death of another have retarded the fruition of labors, which, at least during the administrations of Rominger and Wright, were largely personal.

Of rock samples collected by the Survey previously to Mr. Wright's time, none appear to have been handed down to Mr. Wright. Mr. Wright, in three seasons of field work, during which he spent probably more than half the season between May

and November in the field, gathered some 3,300 specimens of rocks, which, together with others contributed by the Hon. John M. Longyear and other parties representing large land interests in the upper peninsula, formed the nucleus of our present collection. Notes of surveys made by these parties were also placed at the disposal of the Survey and copied into its records; a number of maps and sketches were, in whole or in part, completed by Mr. Wright, to illustrate respectively the topography of the country and its geological phenomena, and descriptions of about two hundred thin sections, made from rocks in the collection, were written by him. In the lower peninsula Mr. Wright visited salt wells, and by the aid of the information gathered there, prepared some sixty sections of deep borings, which appear at the end of this volume. Inasmuch as the office work of the Survey, as above intimated, was largely done by Mr. Wright, without the aid of the corps of assistants that did much of the field work, his term of office was undoubtedly occupied in zealous labor for the State, to equip himself thoroughly for the responsible task of writing up its geology; but, unfortunately for his successors, he left nothing that was available for immediate publication, and many of the facts observed and conclusions reached by him, after years of research and study, died with him, and were thus lost to the public.

During the administration of Dr. Wadsworth the collection was augmented to 7,000 or more specimens, and from many of them thin sections were made, and examined, and written descriptions of several thousands of these were prepared. These descriptions, together with the field work and work on the maps and sketches, that had been going on since Dr. Wadsworth's appointment, leave in the possession of the Survey a large amount of material that, with the necessary acquaintance on the part of the State Geologist with the geological structure of the country, and with sufficient means to push the work rapidly forward, would place the latter official in a position to publish the results of the Survey's investigations with less delay than has heretofore been the case. Some of the results of this work have already been given to the public in Dr. Wadsworth's annual reports to the Board of Geological Survey, and in his "Sketch of the Iron, Copper and Gold Regions," all of which were published by the Board in its report of 1892. The last named sketch was to be revised and

enlarged by Dr. Wadsworth and Mr. A. E. Seaman, and made a part of this volume, but those gentlemen have been unable to complete and furnish the promised manuscript.

The Geological Survey now has a building of its own, in Houghton, partly equipped with the apparatus most necessary to its work. This work, details of which appear from time to time in the annual reports of the State Geologist, may be expected to proceed henceforth under favorable conditions, and will, it is hoped, prove of service to the economic interests of the State.

LUCIUS L. HUBBARD,
State Geologist.

GEOLOGICAL SURVEY,
Houghton, November, 1894.

PART I.

GEOLOGICAL REPORT

ON THE

UPPER PENINSULA

OF MICHIGAN

EXHIBITING THE PROGRESS OF WORK FROM 1881 TO 1884

IRON AND COPPER REGIONS

BY

C. ROMINGER

ACCOMPANIED BY A MAP AND TWO GEOLOGICAL CROSS-SECTIONS

TABLE OF CONTENTS.

CHAPTER I.—Introduction.

Use of terms, Azoic, Archean, Eozoic, Laurentian, and Huronian. Confusion. Criticisms.

CHAPTER II.—Granitic Group.

Deposition of Huronian on Granite Base. Upheaval and Intrusion of Granite. Origin of Diorite. Syenite. Diabase Belts and Dikes. Granite Dikes. Contacts. Recemented Granite. Gogogashung River.

CHAPTER III.—Dioritic Group.

Original Diorites Distinguished from Diabases. Microscopic Characters. Gabbro. Hornblendic and Augitic Rocks. Analogy of Huronian in Gogebic and Marquette Districts.

CHAPTER IV.—Iron Ore Group.

(A) Marquette Region.

Subdivision of Iron Ore Group. Dislocations. Kloman Location. Winslow Mine. Standard Mining Company. Cannon and Erie Mines. Chippeway Mining Company. Magnetic Mine. Wolframate of lime (Scheelite). Staurolite. Age of Ore Deposits. Michigamme and Spurr Mines. Stratigraphical Relations. Chloritoid. Washington, Edwards and Champion Mines.

(B) Menominee Region.

1. Felch Mountain Range. Stratigraphical Succession. Overturn.
2. Menominee and Michigamme Rivers. Older Strata. Ellwood Mine. Keyeslake. Lake Mary. Stratigraphical Succession.

(C) Gogebic Region.

Geological Structure. East of Gogebic Lake. West of Gogebic Lake. Stratigraphical Succession. Galena. Ferruginous Quartzites. Siliceous Schists. Dip of Strata. Sunday Lake. Occurrence of Ore. Infiltration. Analyses of Ore. Montreal River.

(D) Penokee-Gogebic Region, Wisconsin.

Gogogashung River. Analyses of Ore. Stratigraphical Succession. Penokee Gap.

(E) Vermillion Range, Minnesota.

Stratigraphical Succession. Gabbro. Slate. Equivalency with Formations of the Marquette District.

CHAPTER V.—Arenaceous Slate Group.

Economic Interest. Taylor Mine. Plumbago Creek. Slates. Dikes. Lake Michigamme. Northampton and Dalliba Mines. Champion. Clarksburg. Cheshire Mine. Stratigraphical Succession. Quinnesec District. Paint River. Brier Hill Company. Chicagon Lake. Iron River.

CHAPTER VI.—Mica Schist Formation.

Michigamme Lake. Inversion of Strata by Folding. Staurolite Schists. Dikes. Keystone Mine. L'Anse Slates. Lower Michigamme River. Crystal Falls. Paint River. Brule River. Commonwealth Group. Gogebic Lake.

CHAPTER VII.—Keweenaw Group.

(A) General Considerations. Basin of Lake Superior.

1. Structure of the Keweenaw Group. In General. Its Limits. Western Sandstones. Eastern Sandstones the Equivalent of the Potsdam. Persistency of Beds. Thickness of the Formation. Dip. Amygdaloids.
2. South Side of Portage Lake. Isle Royal Mine. Portage Mine. Montezuma Mine. Huron Creek. Atlantic Mine. Conglomerate Belts.
3. North side of Portage Lake. Douglass, Concord and Arcadian Mines. North Star Conglomerate. Houghton Conglomerate. Franklin, Quincy and Pewabic Mines. Hancock Mine. Swede Creek.
4. Northern Part of Keweenaw Point. Hungarian and Douglass Houghton Creeks. Allouez Conglomerate. Albany and Boston Mine. Osceola Mine. Tamarack Shaft. Beds East of Calumet and Hecla Lode. Calumet and Hecla Conglomerate. Kearsarge Amygdaloid. Allouez Mine. Ahmeek Mine. Fissure Veins. Cliff Mine. Eagle River Section. Copper Falls Mine. Phœnix Mine. Central Mine. Delaware Mine. Lac La Belle. Bohemian Mountain. Gabbro.

   Lower Division of Keweenaw Group. Bête Grise Bay. Mount Houghton. Felsite. Montreal River. Porphyritic Diabase. Felsites. Union Bay. Keweenaw Mine. Star Mine. Clark Mine. Manganese. Black Oxide of Copper.
5. Ontonagon District. Flint Steel River. Quartz Porphyry. National and Minnesota Mines. Mass Mine. Ridge Mine. Adventure Mine. Belt Mine. Forest or Victoria Mine. Windsor, Trap and Norwich Mines. Cascade River. Porphyries. Iron River. Nonesuch Mine. Little Carp River. Carp Lake Mine. Cuyahoga Mine. Union Mine. Union River. Nonesuch Group. Iron River. Youngest Deposits of Keweenaw Group. Discordance.
6. Gogebic Lake.

LIST OF PLATES.

PART I.

Reference Map of Western Part of Upper Peninsula of Michigan.
Cross Section of Calumet and Hecla Mine.
Cross Section of Tamarack Shaft, No. 3.

ERRATA.

Part I.

Page 6, 18th line, for "portion" read "portions."
" 6, 5th line from bottom, for "Huronion" read "Huronian."
" 10, 5th line from bottom, for "granates" read "granites."
Pages 10, 53 and 54, "Gogogashung" is otherwise spelled "Gogogashugun."
Page 28, 7th line, for "othoclase" read "orthoclase."
" 44, 10th line from bottom, for "comglomerate" read "conglomerate."
" 26, 23d line, for "McGillis's" read "Gillis's."
" 68, 17th line from bottom, for "heiter" read "either."
Pages 87 and 120, 14th and 6th lines, respectively, from bottom, for "escarpements" read "escarpments."
Page 105, 5th line, for "amygaloid" read "amygdaloid."
Pages 134, 136, 137, and 142, for "Montreal River" read "Little Montreal River," to distinguish it from the stream on the boundary between Michigan and Wisconsin.

CHAPTER I.

INTRODUCTION.

The present report, describing the results of a continued examination of the geological structure of the Lake Superior district, forms a supplement to the previous, fourth volume of reports in which the same district has been the object of description as far as it was then investigated. Meanwhile a much larger area came under observation, which partly was formed of the same rock complex as the one described in the former volume, of the so called Huronian system, partly represented a more recent group of rocks known as the Copper-bearing or Keweenaw group, because it encloses immense deposits of metallic copper and as Keweenaw peninsula is altogether formed of this series of strata.

To communicate the newly acquired information about the Huronian rock series, I thought it best to reconsider the different chapters of the former report and to add to them in each place the concerned facts accumulated by the more recent investigations.

The description of the copper-bearing series is appended in a separate chapter.

I continue to use the name "Huronian" for the entire rock complex of Lake Superior called by Foster and Whitney "Azoic," "Archaean" by Dana, and by the Canadian geologists and their followers "Eozoic," sub-divided in two groups, an older called *Laurentian* and a younger, *Huronian*.

I stated in the previous report that in the Marquette region, where I commenced my investigations, no tenable line of demarcation between an older Laurentian, and a younger Huronian group unconformably deposited on the first, could be observed.

The Laurentian gneissoid and granitic rocks, according to the theory of the Canadian and other geologists, are highly altered former sedimentary rocks. The occurrence of supposed foraminiferous animal remains in limestone belts interstratified with

these gneisses was considered as an infallible proof for the correctness of their theory, but recent unbiased investigation of these supposed animal remains, named Eozoön, has evinced to full satisfaction their inorganic concretionary nature.

The lower granitic and gneissoid portion of the rock group in the Marquette region exhibits the characters of an eruptive and not of an altered sedimentary rock.

The asserted nonconformity between a Laurentian and Huronian division is not observable in that portion of country; even the Canadian geologists dissent on the conformity or nonconformity question and in special instances their opinions, which part of an exposed series of rock beds belonged to the Laurentian and which to the Huronian, widely differ.

This state of confusion was recently censured in a critical review of the literature concerning these older rocks, published by Messrs. Whitney and Wadsworth, in order to vindicate the right of priority for the name "Azoic" rocks instead of "Archaean" or "Eozoic" (Laurentian and Huronian).

The name "Azoic," no doubt, is prior to the others, but at the time it was first used the absence of organic remains in these rocks was just as little proved as the later claimed abundance of them for the same class of rocks then called Eozoic.

The criticisms are intentionally one-sided to suit their purpose.

After their representation of the great confusion of opinions existing with regard to these rocks, one might justly expect a proposal of their own, how to transform this chaos into a harmonious system, but instead of an earnest effort to do this, the book abruptly closes with a sneering proposition.

CHAPTER II.

GRANITIC GROUP.

In the previous report, which commences with a description of the geological structure of the environs of Marquette, I have stated the occurrence of large areas of granite some distance north and south of the city, and the intermediate space from four to five miles in width as being occupied by a large body of massive and schistose dioritic rocks, succeeded upwards by argillitic, chloritic and hydromicaceous schistose layers enclosing lenticular seams of hematitic iron ore, which on their part are overlain by a large quartzite formation and by still higher beds of siliceous limestone interstratified with argillitic or hydromicaceous schists of various color, some of them intensely impregnated with hematitic iron oxide.

All these strata I described as being steeply upheaved in a constant axial direction from east to west and as excessively folded and corrugated, suggesting as the principal cause of these disturbances the uprising of the granite into a synclinal trough, compressing the incumbent sedimentary layers.

I further stated that particularly the lower dioritic portion of the rock beds enclosed within this trough was found intermingled with beds of granite, partly parallel to the stratification, partly transversal to it, from which circumstance I inferred the intrusive nature of these belts and suggested that this intrusion occurred contemporaneously with the upheaval of the granite into a trough, and that part of it at least must have been then in liquid or plastic condition.

Generally, a solid crust of granite probably served as a substratum on which the Huronian sediments were laid down, but not often is occasion offered to see the rocks in contiguity well enough exposed to allow a discrimination whether such contact is an original primary one or resulted from subsequent dislocation.

The existence of granite as surface rock at the time the Huronian sediments formed is proved by the occurrence of belts of granite-conglomerates and -breccias in different horizons of the series.

A large belt of conglomerate, formed of rounded, water-worn granite pebbles and schistose rock fragments, cemented by a matrix of similar schistose material, is seen in contact with a granite belt in the S. ½ of Sec. 2, T. 48, R. 26, but this instance is not a satisfactory example of the deposition of sediments enclosing debris of the underlying rock, as the granite pebbles in the conglomerate are totally different from the underlying granite, which is a porphyritic kind largely composed of a cryptocrystalline felsitic groundmass, enclosing quartz grains and orthoclase crystals of larger size. This peculiar variety of granite is typical for the smaller intrusive belts, and most likely the granite in this case came in contact with the conglomerate belt by intrusion.

Better proof for the deposition of Huronian sediments on a base of granite is furnished by another locality in the S. E. ¼ of Sec. 22, T. 47, R. 26, where several knobs, centrally composed of massive granite, are surrounded by a mantle of coarse granite breccia with a well laminated quartzose material as a cement, which breccia is conformably succeeded by a series of steel-gray colored shining hydromicaceous slate rocks, interlaminated with heavy belts of light colored compact quartzite. Granite-conglomerates are also found interlaminated with dioritic schists remote from granite outcrops. Such a belt is, for instance, observable in the N. ½ of Sec. 29, T. 48, R. 25.

The upheaval of the granite and its intrusion into the overlying strata occurred in all probability near the termination of the Huronian period, as we find the granite in contact with any of the Huronian strata up to the youngest, and these always in a dislocated position.

Intrusive belts of granite are usually not found to intersect beds higher than the iron-bearing group, excepting the country north of the Penokee Range in Wisconsin, and also the vicinity of Duluth, in Minnesota, where granite or granite-like rock seams cut across eruptive belts of gabbro, which themselves are more recent than any of the sedimentary strata reckoned to belong to the Huronian group. These granites differ also some

from the ordinary granites at the base of the Huronian and most likely are younger.

The dislocation of the Huronian beds is not exclusively due to the upheaval and intrusion of the granite, as numerous other intrusive rock belts, dioritic or diabasic, intersect the granite as well as the incumbent beds. The dioritic kind of these rocks is the older, as we see it invariably intersected by the diabasic dykes if they come in contact.

The dioritic belts intersecting the granite are lithologically identical with similar rock belts interstratified with the schists of the Huronian group conformably, or also transversely intersecting them; they represent, therefore, one and the same volcanic injection.

As from the massive form of diorites a gradation exists into a schistose condition, and as schistose structure formerly appeared to me a positive proof of a former sedimentary origin, I resorted, in the previous report, in order to explain the similarity in the composition of these schists with the massive diorites, to the hypothesis of a secondary fusion of the lower beds of sediments nearest the focus of central heat and a subsequent injection of the fused part into the folds and fissures of the remainder of the strata. Simultaneously also I supposed the molten mass to have been forced into the fissures and crevices of the adjoining granite. I have since lost much of faith in this suggestion, as I convinced myself that schistose structure is not necessarily the result of aqueous sedimentation, but that cooling eruptive masses under circumstances can assume a schistose form. Not to be confounded with the above mentioned diorites, common to the granitic portion and the incumbent schistose group, are other belts of hornblende rocks, which are found in association with the granite only, and not above it.

While the first have generally a dull, lighter or darker greenish color and massive appearance, the latter exhibit usually great lustre. Their color is blackish or speckled black and white, and most of them are distinctly laminated, running on one side into hornblende-schists, on the other into a gneiss. The blackish hornblende in them is scaly, often hard to distinguish macroscopically from black biotite, and is arranged in interrupted linear layers alternating with the granular feldspathic and quartzose constituents of the rock. Belts of such rock are seen in

repeated alternation interlaminated with granite belts; at other times both intersect each other in a network of seams; the gneissoid portions often are plicated in zig-zag lines or into serpentine curves; usually biotite enters into the composition and partially replaces the hornblende.

Different again are the syenitic rocks associated with the granite in certain locations. They are coarsely crystalline, consisting of dark blackish hornblende and of orthoclase without quartz. They form separate hillocks scattered over granite areas.

The doleritic or diabasic rock masses, which intersect in dyke form all the Huronian rocks from the granite to the uppermost beds, played an important part of the disturbing elements acting on the Huronian rock series. As above stated, their eruption occurred later than that of the diorite dykes. The color of these dykes is generally black, if they are fine-grained; gray or black and white speckled, if their crystalline structure is coarse. Often in larger dykes the exterior portion near the enclosing walls are almost aphanitic with conchoidal fracture, while the central portions of the dykes are formed of a magma of larger crystals.

Thin sections examined under the microscope show the components of the rocks to be translucid crystals of plagioclase, transparent augite with pale brownish color, and variable quantities of magnetite. In some of these rocks, if not in all, olivine is an additional component.

A striking similarity exists between these dyke masses and the diabase belts, particularly the so called greenstones of the Copper Range; the resemblance in some instances is so perfect that hand specimens or thin sections of the two compared kinds of rock could not be distinguished if no label were attached to them. Furthermore, such dykes not only intersect the strata of all horizons in the Huronian series, but we observe the identical dykes also cutting across the gabbro belts near Duluth, which form the basal part of the Copper-bearing series. Considering these circumstances, I think to be justified to believe that these dykes intersecting the Huronion group, and the overflow of diabase making part of the Copper-bearing formation, originate from the same source and, although not strictly contemporaneous, form a chain of successive volcanic outbursts actually representing one and the same event in the geological history.

During the progress of the survey I re-examined the vicinity of Marquette and found granite dykes to be much more abundant than I previously knew; particularly on Lighthouse Point I noticed the schistose beds to be intersected by a network of narrow granite dykes which had escaped my attention on former visits to the place.

All these dyke masses have not the typical granite structure but are porphyritic, formed of a fine-grained cryptocrystalline felsitic groundmass in which dimly defined larger orthoclase crystals and grains of quartz are dispersed; generally also linear streaks of biotite and chlorite scales are intermingled and a more or less distinctly laminated fluidal structure of the rock is always observable.

Some of the belts cleave into even flags from one-half an inch to two inches in thickness, which by another vertical cleavage are divided into rhomboidal segments the surface of which is generally covered with a thin coating of silvery shining hydromica. Such a belt is well exposed on the north side of the Lighthouse tower, which I had noticed before, but mistook for a sedimentary layer on account of its laminated structure.

On the north limits of the city and two miles west of it, where the granite dykes are much larger, a gradation from the porphyritic structure to the completely finished crystalline form of ordinary granite is readily observable. I generally observed that the smaller belts of eruptive granite have this porphyritic quality. The granite seams intersecting the dioritic rock series south of Upper Quinnesec Falls, on Menominee River, are of the same nature as those near Marquette; the porphyries of Pemenee Falls are perfectly analogous; but in the latter locality it is not only a narrow band but a succession of porphyritic beds of immense thickness. On the other hand also narrow dykes of granite occur which have the completely crystalline structure of a normal granite. One such instance, which has additional interest by the circumstance that the granite dyke cuts across the iron-bearing rock series, which is rare, can be observed in the Felch Mountain region. In the bluffs south of the Metropolitan mine, formed of heavy quartzite beds richly impregnated with particles of specular iron ore, this granite dyke, fifteen or sixteen feet in diameter, cuts in geniculated course through the quartzrock. The rock underlying the quartzites which dip under high angle north-

ward is a gneissoid hornblende-schist, whose intersection by the granite dyke is not visible on account of large accumulations of talus on its slope.

In the vicinity, T. 42, R. 28, Sec. 33, S. W. ¼, another wedgelike intrusion of granite into the iron-bearing rock series is exposed. The concerned rocks form a low ridge trending east and west. On the south side, separated by a swampy depression, high granite bluffs are in close proximity; on all other sides the ridge is surrounded by a swampy bottom. The north side of this ridge presents near its base low bluffs of a dark green gneissoid hornblende rock, succeeded above by a broad belt of a banded hydromicaceous and quartzose rock which by impregnation with a large proportion of specular ore granules has a steel-gray color with bright metallic lustre; some narrower seams are composed almost purely of iron ore. The strata are nearly vertical, but those on the northern edge of the belt dip southward while on the south part of the belt a dip to the north is plainly observable. Beneath this ferruginous belt we find farther south a large succession of dark greenish, smooth-bedded, minutely scaly biotitic hornblende-schists dipping north. Descending in the succession, the mica-leaves and hornblende-scales of the schists become much coarser and copiously intermingled with brown garnet crystals. This portion of the rock is also much corrugated. Next to it projects a lenticular mass of granite associated with gneissoid seams. The granite mass is parallel to the trend of the formation, but lateral branches of the main mass intersect the strata transversely. Crossing this wedge of granite, we find on its south side the garnetiferous mica-schists continued, dipping north like those on the other side farther on; the smooth-bedded, fine-grained biotitic hornblende-schists appear again, seeming to underlie the garnetiferous beds conformably, and conformably below these the metallic, shining, ferruginous strata repeat, leaning in steeply erected position on the base of the southern granite bluffs. We have here evidently before us a series of strata plicated into a synclinal and another anticlinal fold, the latter ruptured by an intruding granite mass, which rock is there the general surface rock and comes on the south end of the exposure in contact with the uppermost ferruginous strata of the overtilted anticlinal fold.

The granites bordering the south side of the Gogebic Iron

Range and of its continuation into Wisconsin, the Penokee Range came under my observation during the progress of the survey. I found them in every respect analogous to the granites of the Marquette country.

The rocks of that part are not so excessively corrugated; the upheaval lifted the strata more in continuous sheets, and belts of granite intrusive in the incumbent strata could not often be observed, although several granite seams cutting across dioritic schists occurred to me about four or five miles west from the shore of Lake Gogebic.

Following the range, the granite is not always found in contact with the same kind of strata; locally heavy quartzite strata are in contiguity with it. The lower layers of them are often represented by a conglomerate filled with rounded granite pebbles or also by brecciated quartzose beds crowded with orthoclase crystals and cemented by a wax-colored hydromicaceous interstitial mass, which rocks resemble granite so much that it is difficult to distinguish the contiguous beds. These rocks correspond accurately with the rocks I have described in the previous report as occurring on the contact line between the granite and quartzite formation in the north part of T. 47, R. 25 (see pages 15 and 16), which I then supposed to be quartzite altered by its contact with the granite into a granite-like rock; now I am more inclined to consider the rock as a recemented mixture of granite fragments mingled with the arenaceous material which formed the overlying quartzite beds; still it is very singular that the orthoclase crystals copiously imbedded in the mass have all sharp outlines and look as fresh as if they had formed where they are and could not be the debris of a disintegrated granite.

At the above mentioned locality in the N. W. ¼ of N. E. ¼ of Sec. 24, T. 47, R. 43, this singular rock in contact with the granite contains locally an abundance of brownspar which on exposed faces of the rock weathers out, leaving behind ochreous matter which fills the spaces formerly occupied by the spar. Crevices in the rock mass are replenished with galena; explorers have therefore worked considerably in such places and made better denudations than nature would have offered to an itinerant geologist. Only a short distance from the above described locality, in the adjoining Sec. 23, the granite is seen in contiguity with dioritic schists of a brecciated character which enclose

large angular blocks of massive diorite of various quality. The granite comes there also in contact with massive diorite belts and intersects them in dyke form. From here westward I followed a trail which frequently leads over dioritic rocks, but never comes far enough south to reach the granite.

In T. 47, R. 46, Sec. 13, the granite is found in close proximity to cherty banded ferruginous beds enclosing seams of good iron ore; below these iron-bearing beds are light colored kaolinitic strata which are in direct contact with the granite. Further west, in Sec. 15 of the same town, the granite comes very close to the ore-bearing quartzite formation in which extensive exploring pits are opened, but I had no opportunity to observe in this place which sort of rock came in contiguity with the granite. The explorers informed me that diorite formed the footwall of the quartzites in which the ore deposits are found, and the diorite joined on the south side the granite. Onward to the west the explorers made to me the same statements, always speaking of dioritic rocks intervening between the granite outcrops and their exploring pits.

Near the Montreal River in the N. W. ¼ of Sec. 27, T. 47, R. 47, I found granite in immediate contiguity with the ore-bearing quartzite and banded jaspery beds.

In Wisconsin, above the island in Gogogashung River, a belt of schistose dioritic rocks intervenes between the granite and the large succession of light colored slaty rocks which form the island. Above these slate rocks are quartzite strata partly brecciated and interwoven with seams of limonitic iron ore. From here to Penokee Gap I did not make any observations regarding the contact line of the granite with other rocks, but at the Gap in the bed of the river, under a railroad bridge, the direct superposition of crystalline limestones (enclosing tremolite fibres) on the granite could be seen. Above the limestone succeeded some beds of quartzite and then a large series of light colored silico-argillaceous schists, which most likely are identical with those composing the island in Gogogashung River. The granates found on Bad River, north of the Gap, I have previously mentioned, and suggested their age to be younger than that of the granite at the Gap, which opinion agrees with the views of the geologists of Wisconsin.

CHAPTER III.

DIORITIC GROUP.

The extension of the survey over a much larger territory than had been examined at the time the previous report was published did not necessitate any essential alteration of my former views concerning this group, but it furnished ample corroborating proof for the correctness of formerly made statements. Local and regional differences of analogous rocks in different remote places were observed, but this is generally to be anticipated in the examination of any rock formation.

The occurrence of lithologically identical belts of diorite in association with the rock series called the dioritic and with the granitic group, and the frequency of intrusive granite belts in the first mentioned group, make it difficult to draw a line of demarcation between the two; their genetic history is too closely allied. I repeat, therefore, what I stated in my first report: "The subdivisions I proposed for the Huronian group were arbitrary, simply made for convenience in the description of related facts." In recent publications of microscopical lithologists who examined rock specimens of the Lake Superior region, without ever having been near it, I see the opinion advanced that the majority of rocks formerly considered to be diorites are in reality diabases, or originated from diabases by paramorphosis.

As I had described the rocks to be mostly genuine diorites, relying on a macroscopical examination, I was particularly interested to ascertain by the microscopical method of studying rocks, whether I was right, or whether these deductions from a comparatively small number of hand specimens really told the truth. During the progress of my work I therefore took particular attention to examine rocks of this class wherever I met with exposures, with regard to the conditions under which they occurred, and to collect as many of them as possible as hand

specimens for future microscopical examination. These examinations, although only accomplished with the smaller portion of the collections, are sufficient to convince me of the correctness of my former statements, namely, that the crystalline rocks which form the principal bulk of the Huronian rocks, comprised by me under the name "dioritic group," and all the older intrusive rock belts intersecting the granite subdivision are genuine diorites, composed of hornblende and plagioclase. Uralitic diorites, in which the hornblende is supposed to be an alteration product of augite, are not missing, but comparatively they are rare and represent, as far as spacial extension of the rock masses is considered, only an inconsiderable part of the totality. Furthermore, I observed in several instances where such uralitic rock belts occurred, an intersection of the ordinary diorite by them, which, if this should be found to be the case generally, would prove their more recent eruption and probably their intimate relationship with the doleritic or diabasic dykes mentioned in the previous chapter, which dykes, although in some portions of Lake Superior region quite abundant, contribute as a surface rock comparatively only little to the augmentation of the dioritic mountain masses. These augitic rocks were also never confounded by me with the diorite. The massive crystalline rock belts which compose the great bulk of the so called dioritic group in association with schistose rocks formed of almost the same constituents, with addition of another aluminous silicate, the hydromica, are mainly a combination of plagioclase feldspar with hornblende.

The proportions in the mixture of these two minerals are very variable; sometimes the plagioclase considerably prevails, other times the hornblende; oftenest both minerals balance each other approximately. The structure of these rocks varies from a fine, almost aphanitic grain to a very coarsely crystalline condition, in which both minerals are readily distinguishable by the naked eyes.

The plagioclase in nearly all these rocks is turbid, milky or transparent; portions are permeated with white, impellucid masses resembling in form lumps of curdled milk. Frequently the plagioclase exhibits not the shape of larger crystals but appears under the form of a minutely crystalline, granular, interstitial mass; sometimes however even this granular, interstitial plagio-

clase mass is under the microscope seen to be combined into larger crystal individuals not noticeable with the unarmed eyes on account of their turbidity and curdled interior. Only exceptionally the plagioclase crystals are in the condition to show their twinned structure by striation and chromatic polarization under the microscope.

The hornblende in all these rocks has a green color, lighter or darker. It is always more or less inclined to a fibrous structure; its facets therefore have never the smooth lustre of a mirror, like for instance the hornblende of the basalts, but it is a satin lustre; often also the lustre is very dull. It rarely forms completed crystals; usually the crystals are terminating on both ends in a torn, brush-like manner, or they are densely interwoven so as not to allow a distinction where one individual crystal ends and the other begins. Most of it displays a strong dichroism under the polarizer, but in the lighter colored varieties the dichroism is sometimes scarcely perceptible. In some of the rocks the hornblende is partially replaced by an earthy green substance called viridite, or by a chlorite-like mineral, both of which are considered to be decomposition products of the hornblende. Almost without exception, a number of granules or of clusters of granular crystals of titan-iron are found disseminated through the dioritic rock mass and usually these clusters of impellucid black colored grains are surrounded by a bluish white semi-transparent mineral, titanate of lime, which is most likely resulting from decomposition of the grains of titan-iron. Sometimes the titan-iron is replaced by magnetite and then its surroundings are tinged rusty brown.

Dispersed clusters of little cubes of iron pyrites are found in nearly all the diorites; sparingly scattered grains of quartz often occur, and in many diorites epidote is an accessory constituent. It is sometimes in portions of the dioritic rock masses very abundant and probably is a secondary product of alteration, not an original constituent. In the same manner also calcspar enters into the composition of diorites; likewise hydromica. The latter mineral seems to be the product of a paramorphosis of hornblende. In one instance at least, I found a soft, silky hydromica-schist which crops out on the wagon road from Negaunee to Ishpeming in association with massive diorites, to have been an aggregate of interwoven crystals of hornblende which had decolorized.

These crystals having the characteristic cleavage of hornblende, when crushed by pressure of the fingers dissolved into fatty-feeling transparent scales corresponding in every respect with hydromica. As in most of the dioritic schists, hydromica largely enters into their composition. I am inclined to suppose that the schists so intimately associated with massive diorite belts are a product of their decomposition under circumstances favoring the schistose arrangement of the molecules, or to speak in more definite terms, are a modified form of these eruptive masses and do not represent former sedimentary deposits.

Besides these genuine diorites, which as above stated are largely prevailing over diabasic rocks, I found during the microscopical examination of a great number of specimens comparatively few, in which, besides the hornblende, also augite entered into their composition.

In some of them the hornblende and the augite appeared to be independent original constituents, but in others the augite seemed to have been the primary mineral which seemed to have suffered partial transformation into hornblende. In external aspect the augite-bearing diorites are not discernible from the others; their nature became only known to me after examination with the microscope. Of diorite specimens examined found to be augite-bearing, I mention the following localities where I found them: T. 47, R. 26, Sec. 10, near center and in the N. W. ¼ of the Sec.; T. 47, R. 26, Sec. 18., S. W. ¼ of S. W. ¼; T. 47, R. 26, Sec. 7, S. W. ¼ of N. W. ¼; T. 47, R. 26, Sec. 15, S. E. ¼ of N. W. ¼; T. 47, R. 28, Sec. 13, N. W. ¼ of N. W. ¼; T. 42, R, 35, Sec. 13, N. W. ¼ of N. W. ¼. The fine-grained dioritic rocks at or near Quiver Falls on the Menominee are all augitiferous; also the range of diorite running across the N. ½ of T. 40, R. 30. The hornblende in them appears to be the result of alteration of the augite. The five first mentioned localities are all not far apart in the surroundings of Negaunee. Whether these eruptive belts are contemporaneous with the other diorites or whether they are younger dykes intersecting them I have not been able yet to ascertain, for the above mentioned reason that the augitic character of the concerned rocks was not recognized by me while in the field.

Still more rare is the occurrence of gabbro, or plagioclase rocks in which diallage takes the place of hornblende or augite as in

the diorites and diabases. I have here reference to rocks supposed to be contemporaneous with the dioritic rock masses, and not to the gabbros above mentioned as eruptive belts much younger than the diorites, which latter, in some parts of Lake Superior region form whole mountain ranges.

In my previous report I described the rocks exposed at Upper and Lower Quinnesec Falls and those forming the barrier of Sturgeon Falls on Menominee River as diorites, relying on macroscopical examination of the coarse-grained varieties of these rocks which, according to Credner's and Pumpelly's statements, were diabases or gabbros.

Recent microscopical examination of these same rocks convinced me that I was in error with regard to the barrier rock of Sturgeon Falls which has the composition of gabbro, but the rocks exposed at Upper and Lower Quinnesec Falls are typical diorites. Portions of the barrier rock of Sturgeon Falls contain, besides the pale greenish gray diallage, also dark green strongly dichroic hornblende prisms; locally even the hornblende replaces the diallage altogether.

Below Sturgeon Falls other rocks of gabbro composition are largely exposed in Sec. 35 of the same town; they resemble the barrier rock by their white and greenish gray speckled appearance, but the magma of crystals is much more minute.

Several miles lower down on Menominee River, in the N. W. ¼ of Sec. 16, T. 38, R. 28, another gabbro belt occurred to me, which resembles an ordinary dark colored diorite, quite unlike in appearance to the barrier rock at Sturgeon Falls. Thin sections of the rock show its composition of about equal proportions of transparent prisms of plagioclase and of green colored most delicately laminated blades of diallage filling the interstices left between the plagioclase crystals. Diallage appear also as a constituent of certain beds of the serpentines which intersect the dioritic series in dyke form a short distance above Sturgeon Falls.

Exposures of a dark, blackish green massive rock, composed of an agglomeration of large blades of diallage with an interstitial cement of green colored serpentine are in the S. W. ¼ of Sec. 26, T. 39, R. 29, next to the road leading to Menominee; other quite fine-grained rock seams found in association likewise consist of a groundmass of serpentine crowded with minute scales of diallage. In rocks of minutely crystalline structure it is often

difficult to make the distinction between hornblende and diallage, as the paler colored hornblende exhibits only a faint dichroism and has the same laminated appearance in thin sections as the diallage; the angle of intersection of the hornblende cleavages is also not always observable in the thin sections.

In the latter mentioned rocks of almost aphanitic grain, I based the determination of diallage in their composition on their intimate connection with the coarser crystalline diallage-bearing rock masses; otherwise the scaly leaflets had just as much resemblance to a light green colored hornblende. The rocks largely exposed in Sec. 12, T. 39, R. 30, are also mingled with diallage blades. The greenish gray, middling-fine grained rock consists of a groundmass of granular plagioclase in intermixture with large quantities of magnetic granules, besides interstitial patches of serpentine-chrysotile. Within this crystal magma numerous blades of diallage and clusters of olivine grains are copiously disseminated.

On page 219 of the previous report I gave a description of several coarsely crystalline rocks occurring on the Menominee River in T. 37, R. 28, Sec. 9, about three-fourths of a mile above Pemenee Falls, which were based merely on macroscopical examination, and require a correction after I examined thin sections of them under the microscope.

These rocks, found in the same locality, evidently represent two different kinds of eruptive masses.

The blackish colored rock of porphyritic structure, just described, is an augitic and not a hornblendic rock, as I had supposed. It is composed of a fine-grained groundmass of plagioclase, part of which is turbid, granular, part is transparent, exhibiting sometimes polysynthetic striation, but usually these transparent portions on revolution between crossed nicols become dark and light, but show no bright colors.

Within this groundmass are irregular, rounded, transparent grains copiously disseminated, which exhibit bright, chromatic polarization and are probably augite microlites; with them occur plenty of colorless apatite needles.

Other much larger transparent grains scattered through the groundmass in clusters consist of olivine; they are intersected by a network of capillary seams in which dustlike magnetite granules have accumulated; their color is pale yellowish.

Macroscopically visible are large augite crystals, perfect all round, often twinned and composed of concentric zones, one enveloping the other. In thin sections they are transparent, with greenish brown or yellowish color; they often inclose grains of olivine. Magnetite granules are abundantly disseminated through the whole mass, and small irregular dots of the rock mass are purple-colored from infiltration of ferruginous pigment.

The other rocks described on the same page as coarsely crystalline hornblende rocks, are of particular interest by the intimate combination of their hornblende with augite, which plainly exhibits all the gradations of the paramorphic process from augite into hornblende.

The freshest-looking of these rock masses consist almost exclusively of an agglomeration of brightly shining, dark colored hornblende crystals with only a small proportion of turbid white or cloudy reddish colored feldspar crystals in the interstices left between the hornblende crystals, besides some scattered blades of dark greenish colored biotite.

In thin sections the hornblende crystals are transparent with greenish brown or yellowish color, perfectly clear, homogeneous if the section is parallel to the cleavage, longitudinally striated if the section is vertical to the cleavage. The crystals enclose numerous clusters of grains of magnetite which often have a singular lobate or also horseshoe form, and very thin sections show these agglomerations of granules to be cemented by a transparent interstitial mineral.

In these fresh rocks only few of the hornblende crystals exhibit a dull greenish white blotch in the center, which under the microscope discloses itself as almost colorless augite intersected by a network of capillary seams, from which emanate fibres of faintly green colored hornblende piercing the transparent augite mass; besides there are also scales of dark colored homogenous hornblende lodged between the augite mass so as to be in correspondence with the cleavage of the exterior hornblendic shell of the crystal.

Other portions of the same rock belt are dull, little reflecting the light, and appear to be in a more or less advanced state of decomposition. On close inspection the main mass of the agglomerated crystals is formed of the above described pale

greenish colored seamy augite, permeated by blades of dark green hornblende, so arranged as to reflect the light simultaneously in certain positions corresponding with the angle of hornblende, while at the same time not rarely the almost rectangular prismatic form of the original augite crystals is observable.

The transformation of the augite into hornblende proceeds in different modes, the most regular of which consists of a uniform alteration of an augite indivual from the periphery toward the center into a single homogeneous hornblende crystal, where the peripheric part becomes first completely changed into dark colored, brightly shining hornblende substance, which gradually infringes on the central, almost colorless kernel of augite by pushing its sharply defined lobate projections deeper and deeper into the mass, which shows the first signs of alteration by assuming a pale grass-green color and a fibrous structure in parallelism with the finished exterior shell of the crystal, while isolated fragmental blades of dark colored hornblende form also centrally, which enlarge on their margins and finally coalesce with the outer part into one large cleavage plane of the crystal.

In other instances the hornblende commences to form in interwoven needle-shaped prisms permeating the augite in radiating clusters, which process does not result in the production of one crystal individual imitating the shape of the original augite crystal, but terminates into an agglomeration of hornblende fibres.

A portion of the uralitic rocks is further advanced in alteration by transformation of the augite into an earthy hematitic substance, which alteration attacked only part of the crystals, leaving the others intact. The very fresh aspect of the rocks formed of hornblende free of augite, and the dull, easily disintegrating condition of the augite and hematite portions irresistibly impress the observer with the idea of the primary existence of the first and the derivative origin of the latter, but after quiet consideration one can very well conceive the rotten appearance of the original augitic material and the freshness of the product resulting from its decomposition. I was under such erroneous impression when, on page 213 of the previous report, I stated the intimate intermixture of very fresh tremolite crystals with more or less decayed crystals of sahlite, and inferred the sahlite to be an alteration product of the tremolite.

The extension of the survey into the Gogebic district showed to me a perfect analogy in the structure of the Huronian series with the Marquette or the Menominee region.

North of the granite range previously mentioned, in many, but not in all localities, a large body of schistose and massive dioritic rocks overlies it, dipping to the north, and forms the base on which the iron-bearing rocks repose. More rarely the dioritic rock belt is found missing and the iron rocks follow immediately above the granite. The dioritic rock group there amounts to a considerable thickness. Most of the diorites are fine-grained, and some of them very light colored, almost totally composed of granular plagioclase; rocks of this kind are largely exposed along the north line of Sec. 23, T. 47, R. 44. Associated with singular compact rock belts of coarsely brecciated structure composed of large and small angular blocks of various kinds of diorite cemented by a seamy interstitial mass very similar in composition to the inclosed dioritic fragments, numerous milky plagioclase crystals of large size, or also rounded concretionary nodules of feldspar have segregated in it. Calcspar likewise sometimes enters freely into the composition. The cementing groundmass exhibits a distinct fluidal structure, as if the rock fragments had been stirred into it while it had the plasticity of a dough. The fresh-fractured rock resembles a compact porphyritic diorite, as the color of the rock fragments and their cement do not differ much, but on the weathered face of the rock the brecciated composition and the fluidal structure of the cement mass become very obvious.

Large bluffs of the same kind of breccia are also exposed on the side of the trail near Mr. Gillis's camp in T. 47, R. 43, along the north line of Sec. 23; it forms there the footwall of the galena-bearing quartzite formation, the lowest beds of which are a coarse conglomerate of quartz pebbles of various color. South of these outcrops a large succession of massive and schistose dioritic beds follow, then granite follows in close contact with them.

Near the south end of Gogebic Lake and east of it, in T. 46, Rs. 42 and 41, other large exposures of dioritic rocks occur, which dip in an opposite direction southward; they are conformably overlain by an ore-bearing sedimentary rock series. The eruptive nature of the diorite is proved by the occurrence

of belts cutting transversely through the ore-bearing rock series in the vicinity. North of the diorite, according to their southern dip, exposures of the lower granitic rocks should be expected, but none are visible, as all the surface in that direction is covered with drift deposits. Two miles north of the diorite outcrops, after passing over a belt of lowlands, a range of hills rises which is formed of steeply erected ledges of the copper-bearing diabase, dipping north; it commences in the south part of Sec. 30, T. 47, R. 41, and extends eastward, as I am informed by explorers acquainted with this region, for about 30 miles without being much interrupted. This is the so called South Trap Range.

It was at first my intention to give at the end of this chapter a detailed description of all the microscopically examined rock specimens of this group, but after writing such descriptions, I saw they necessarily involved an endless repetition of nearly the same facts. As the specimens amounted to over two hundred, I discarded this plan, too tedious for the reader, and refer those who would have an interest to know the results to the museum of the University of Michigan, where the sections and hand specimens appertaining to them are deposited.

CHAPTER IV.

IRON ORE GROUP.

(A) MARQUETTE REGION.

In the former report I designated with the above name the strata succeeding above the dioritic group, as they inclose the rich deposits of specular and magnetic ore found in the Marquette district. This name has become ambiguous since the discovery of equally large and perhaps larger deposits of iron ore in higher horizons of the Huronian series, and should be amended into "Lower Iron Ore Group."

Reviewing the old established mining district between Negaunee and Lake Michigamme, I find during the time passed since the publication of the last report many discoveries made concerning the local extent of the ore-bearing beds; in particular has been demonstrated by facts the uninterrupted extension of the northern belt of the synclinal trough of ore deposits from the Excelsior mine westward beyond the west line of T. 48, R. 28. From a number of new mining pits opened on that belt at present a very good quality of specular ore is sent to the market.

No new facts however which would essentially alter the previously delineated structural features of the formation have to be reported.

In some places east of the Boston mine the strata which have in that mine a dip to the south are perfectly tilted over and dip northward, the younger beds occupying positions below the older ones, which excessive local dislocation appears to be caused by the eruption of doleritic rocks largely exposed there in dykes intersecting the ore-bearing beds. The superficial portions of these doleritic masses are in a friable decomposed condition representing a white and brown speckled absorbent kaolinitic mass in which the external shape of the former plagioclase and augite

crystals is yet preserved. The occurrence of a similarly decomposed dolerite belt on the Jackson mine property near the south line of S. E. ¼ of Sec. 1, T. 47, R. 27, associated with the manganiferous hematite ore deposits is noted on page 76 of my former report.

By recent explorations at the foot of the knobs northeast of the Negaunee iron furnace, the same doleritic rock, but in perfectly fresh condition, has been struck by a shaft and was at first by the miners erroneously taken for a representative of the quartzite in the hanging of the specular ore deposits; further sinking in the rock soon proved the mistake.

I owe yet the description of a number of mining locations on the Michigamme river north of the Republic mines, which at the time of the publication of the previous report I had not examined; all of them were also then abandoned.

Subsequently several parties undertook to re-explore these grounds, partly by test-pits, partly with the diamond drill, which work was a great help for me in the study of these localities. The results of these explorations were, at the present depressed condition of the iron market, not considered favorable enough to resume in any of the examined places actual mining operations, although in several of them a good quality of bright specular ore resembling that of the Republic mine was found.

Holding detailed review of these localities in going from the Republic mine up the river road, we meet, past the Kloman location, which has been described before, a number of exploring trenches and shafts in the N. E. ¼ of Sec. 2, T. 46, R. 30, in which, under a cover of drift several feet in thickness, quartz-banded specular lean ore beds dipping in an almost vertical position northeastward are found, which from time to time inclose, in the alternation of seams, larger lenticular masses of apparently pure specular ore and likewise thick heavy beds of quartzite. Close examination of these bright ores proves them, however, to the greatest extent so much contaminated with quartz grains that their market value is very small and mining operations were therefore discontinued.

Farther on, in the S. W. ¼ of Sec. 35, and the N. E. ¼ of Sec. 34, T. 47, R. 30, the hillsides to the left of the road present large exposures of dioritic rocks in brecciated intermixture with fragmental masses of well laminated garnetiferous mica-schists

of dark green color and with other schistose rock fragments of chloritic, actinolitic and quartzose feldspathic nature. At the same time, dykes of a coarsely crystalline granite frequently are seen to intersect the brecciated dioritic rock belt.

In the N. E. ¼ of Sec. 34 is the abandoned Winslow mine, on which location a jasper-banded lean ore belt in a vertical position crops out in close contact with granite bluffs. A deep shaft is sunk into this vertical banded lean ore belt which, as could be expected beforehand, remaining in the same beds all the time, proved to be a total failure.

Next north we come to the likewise abandoned exploring pits of the Standard Mining Company, which employed the diamond drill on their explorations, besides digging test-pits. The banded lean ores in association with compact quartzite belts and with highly micaceous silvery shining quartz-schists, are the beds seen in the exposures. Small seams of good specular ore of slaty structure and of a very compact fine-grained steel-colored ore were met with in the banded ferruginous part of the series, but it does not appear in quantities great enough to be mined profitably.

Proceeding further north on the river road, we pass over drift-covered terrace lands bordering the river, with bluffs of dioritic rocks associated with garnetiferous, actinolitic mica-schists, visible a short distance to the left of the road. In the N. ½ of Sec. 28 we leave the river side and ascend by a path the hill on which we find the Cannon and Erie mines located. The Erie mine comprises the N. E. ¼ of the N. W. ¼ of Sec. 28; all the remainder of the section is Cannon property. The openings of both mines are close together on the dividing line between the properties. The general trend of the strata is from southeast to northwest; dip under a high angle northeast. The succession of beds in descending order is as follows: First, forming the upper part of the slope towards the river, a succession of heavy, light colored, whitish, quartzite beds interstratified with thinly laminated micaceous quartz-schists and with seams of soft mica-schist of great silvery lustre is exposed or found under a thin cover of drift masses. The thickness of this belt is about 200 feet.

Next below succeeds a dark colored rock belt with metallic lustre, about 80 feet wide, consisting of alternate narrow bands of granular or jaspery quartz, red or dark gray colored by impregnation with hematitic pigment, and thinly disseminated specular ore

granules, and of other bands almost entirely composed of ore granules with a smaller proportion of quartz grains intermingled. Locally these ore seams widen into large lenticular masses of specular slate ore; in some of them, however, a portion of the mica-like scales of the ore are replaced to a great extent by true mica. A similar transition of slate ore deposits into mica-schists comparatively poor in iron is also observed in other locations, as for instance in the western pits of the Washington mine.

Beneath this iron-bearing rock belt follows a large series of light colored mica-schists of great lustre, partly in soft fatty-feeling layers, partly hard and gritty by admixture of granular quartz, particularly in the lower horizon where the quartz predominates. Finally the schists are succeeded by compact quartzite beds, which latter layers are locally shattered into fragments and with intermixture of other quartzose, dioritic, and granitic rock pieces are re-cemented into a very coarse breccia, which encloses also rounded concretionary masses formed of hornblende crystals, which concretions gradually merge with the surrounding quartzite plasma by plentifully dispersed single hornblende prisms in their circumference becoming more and more distantly scattered in proportion with their remoteness from the concretionary nucleus of hornblende. These beds are well exposed on the dividing line between the two mines and are at the same time seen in contact with an eruptive diorite belt which crosses the strata transversely and, probably, caused by its eruption the great disturbance and shattering of the beds. We see in the mining pits opened there large segments of the banded lean ore belt, of mica-schist, micaceous quartz-schist and of actinolite-schists impregnated with magnetic ore in irregular hap-hazard position intermingled, with retention of the stratified order of the individual segments of the rock belt; interstitial between them is a network of tortuous bands of garnetiferous dark green colored mica-schist, which, together with branching dykes of the diorite, make the chaos complete.

Some distance further west in other pits of the Erie mine a little less disorder in the relative positions of the beds is observed; still, the dislocation and confusion of the strata are yet so great as to interfere seriously with the mining according to a systematic plan. Serpentine plications and unexpected fault-

ing of the beds are a constant annoyance for the miner, and also considerably increase the expense of mining.

A few hundred steps south of the mining pits a row of granite bluffs is seen to follow the trend of the formation. North of the pits is a low ridge of diorite striking east and west, obliquely intersecting the ore-bearing strata. The before mentioned dioritic rock associated with the greatly disturbed beds in the mining pits on the line between the Erie and Cannon mines forms a side branch of this larger diorite belt.

The present exploratory work of mining at the Erie location had the success of demonstrating the occurrence of lenticular seams of specular slate ore and others of a granular magnetic ore within this rock series sufficiently large, as it appears, to be profitably mined. The large ore piles hoisted there look as bright as the best ore of the Republic mine, but it is on close examination much more contaminated with silica, and only part of it ranges as first-class, high-graded ore. The above mentioned frequent occurrence of faults or abrupt plication of the strata is a circumstance making mining operations uncertain in that locality and has to be considered in estimating the value of the location. On the east side of the river opposite the Cannon and Erie mines, in the S. W. ¼ of Sec. 22, T. 47, R. 30, is the Chippewa mining property, where in former years considerable exploring work had been done, not with the expected favorable results, however.

Starting from the Erie mine, after having crossed the river and an adjoining drift-covered elevation, we find on a second low ridge exposures of a large succession of quartz-banded lean ores interstratified with silvery shining, minutely scaly mica-schists, and beneath them follows a broad belt of garnetiferous mica-schists, some layers fresh, dark green colored, smoothly laminated, or elsewhere much twisted and corrugated; other strata are in a decomposed condition, lighter brownish colored and the enclosed garnets changed into a rusty, friable, earthy mass.

Underlying these succeeds a wide belt of light colored, thick-bedded, more or less micaceous quartzites, and further east, after interruption of the outcrops by a narrow, swampy depression, we find gneissoid and granitic rocks intersecting each other in transverse belts to form the general surface rock.

The strata have a southwest dip in synclinal opposition to the strata of the Erie mine, but do not seem to represent the synclinal counterpart of them; as compared with them, their succession is in inverted order; the large quartzite belt supposed to be the equivalent of the quartzite overlying the beds of the Erie mine is here lowest, and the ore-bearing beds rest upon it. A perfect overturn of the series, therefore, suggests itself. No larger seam of high-graded ore worth mining has been discovered in this locality.

The hitherto described ore-bearing rock belts all seem to be analogous to the layers of the Republic mine.

Returning to the west side of the river, we find at a distance of about a mile and a half northwestward and a half mile off from Michigamme River, another mining location called the Magnetic mine (S. E. ¼ of N. W. ¼, Sec. 20, T. 47, R. 30), where, at the time of my visit, a diamond drill was at work on the drift plateau next to a range of hills on the west side, about 60 feet high.

The cores of the drill, which had reached the vertical depth of 400 feet, showed so far the penetration of dark green micaceous hornblende rocks disseminated in some levels with an abundance of red garnets and intermingled with streaky seams richly impregnated with magnetic ore granules. The ridge on the west side of the drill hole consists of the same kind of hornblende rock.

The obscurely stratified rock masses dip under an angle of about 45 degrees to the north. On the summit of the ridge the strata break off abruptly, and on the west side a stairlike descent is made into the narrow valley of a small creek, where next underlying the hornblende rock compact micaceo-feldspathic ledges follow. Below them are dark green colored schistose beds consisting of brightly shining biotite leaves in intermixture with rather large brownish red garnet crystals.

These are conformably succeeded by a very large succession of well laminated, banded quartzose, actinolitic layers, richly impregnated with magnetite, which inclose larger and smaller seams of magnetic ore locally widening into pockets sufficiently large enough to invite mining operations. The thickness of this succession of actinolitic beds is not less than about 800 feet. The ore masses in the pockets are intersected by seams solidly

filled with interwoven crystal blades of bright green hornblende associated with large brown garnet crystals, with quartz and calcspar, and with nests of tungsten (wolframate of lime), a mineral which to my knowledge never was found before in any of the mining localities of Lake Superior. West of the Magnetic mine extensive explorations for the same ore deposits are in progress near the quarter-post on the east line of Sec. 19, in which place the succession of beds below the ore-bearing strata is better exposed than on the Magnetic mine. These lower beds are well laminated micaceous quartz-schists of silvery lustre, similar to those resting on the ore-bearing rock series of the Erie mine, and amount to a thickness of from 700 to 800 feet. The lowest bed of the series is a compact ledge of quartzite which rests immediately on granite. Other exploring work has been done in the south part of the N. E. ¼ of Sec. 20, T. 47, R. 30, by the same parties who opened the Magnetic mine. We find there the same rock series exposed as in the other two localities, but as this place compared with the location of the Magnetic mine, situated in the S. E. ¼ of the N. W. ¼ of the same section, is much farther to the north, the formation must have been subject to a faulting of many hundred feet intermediate between the two mining openings.

Going from the last mentioned mining pits across the strike of the formation northeastward, I found after passing some distance over drift-covered lands near the northeast corner of the section, a row of knobs about 50 feet high, which consisted of vertically erected beds of the typical staurolitiferous mica-schists striking in a direction approximately north and south. The staurolite occurs in these mica-schists rarely in the form of well defined crystals, but in lenticular concretions often as large as a hen's egg. Breaking them, their grain is not homogeneous, like that of a crystal, but holding the fracture in a certain direction to the eyes the grains of the substance reflect the light all simultaneously, with great lustre. Under the microscope an aggregate of brownish colored and colorless grains with chromatic polarization is noticeable, the exact nature of which I have not determined, excepting the fact that no quartz grains make part of this mass; the colorless grains break the light all at once in the same way, changing in revolution under the polarizer their color into indigo blue, but not running through any

other color, except a darkening. At the northwestern corner of the same section a large body of crystalline rocks, which have a laminated gneissoid structure, forms a cluster of knobs; the strata have a northern dip conformable with the ore-bearing beds at the Magnetic mine, from which they are separated by an intervening drift-covered space. They consist mainly of a groundmass of feldspar crystals, probably othoclase, and of fibrous blades of green hornblende with some biotite scales intermingled; the feldspar much exceeds the hornblende in quantity. These rocks hold an intermediate position between the staurolitiferous mica-schists exposed at the northeast corner of the section and the strata of the Magnetic mine; they are altered sedimentary rocks, as well as the next lower belt overlying the ore-bearing beds of the Magnetic mine, which latter, by their massive crystalline form, have much resemblance with eruptive rock masses. Thin sections of the latter rock examined under the microscope show its composition of a mixture of quartz and feldspar grains with about an equal quantity of interwoven lacerated prisms of green hornblende, besides scattered biotite scales and more or less abundantly disseminated magnetite granules. The ore range on which the Magnetic mine is situated describes an arch trending from the mine, first west toward the quarter-post on the east line of section 19, and thence southward to the center of section 31. Inside of this arch are several granite hills. The ore of the Magnetic mine resembles the ore of the Michigamme or that of the Spurr mine.

Analysis of select specimens of the ore gave 65 per cent metallic iron; 9 per cent were impurities, principally quartz grains and mica scales; the amount of phosphorus is small.

Large burrows of ore are piled up at the mine, but to my knowledge none has ever been sent to the market from this place and work is suspended in it since several years.

These ore deposits are younger than those of the Erie or of the Republic mine. The higher position of the ore beds of the Magnetic mine than those of the Erie mine is directly traceable by following the outcrops of micaceous silvery shining quartz-schists which underlie the ore-bearing actinolite-schists of the magnetic mine, in the direction of the Erie mine, where we will find the same micaceous schists in the hanging of the Erie mine rock series.

The magnetic ore of the Michigamme and Spurr mines occurs likewise in a lower horizon than that of the Magnetic mine, but the actinolitic rock belt succeeding above the actually mined beds of these locations, corresponds in its relative position and in its lithological character fully with the group of beds disclosed at the Magnetic mine.

On special comparison of the mentioned localities I found to my surprise a discrepancy in the succession of beds which I could not explain, considering that the distance between the compared localities is only a few miles.

The case is: South of the actinolite schists at the Michigamme mine I saw, in conformable position succeeding, a large complex of ferruginous cherty beds interlaminated with seams of limonitic ore and with graphite schists, and farther south outcrops of a succession of mica-schists in conformable position with the former; did therefore not doubt then for a moment the interstratification of this belt between the actinolite-schists and the higher mica-schists. On the other hand I found, in the succession of beds above the Magnetic mine, the mica-schists to be the next, without a trace of an intervening rock series comparable to that in the other place, more than a thousand feet in thickness.

Farther inquiry taught me that there was no anomaly in nature, but that my observations were imperfect and misled by the theoretical notion which I had with regard to the position of the so called mica-schist formation, thinking it to be the uppermost complex of sediments in the Huronian series, in accordance with Major Brooks's views.

The actual state of things is: The mica-schists are the next succeeding layers above the actinolitic rock belts of the Michigamme mine and of the Magnetic mine; the large series of graphite schists and limonite-bearing cherty beds are younger deposits conformably resting on the mica-schist series, which is well developed on the south side of the actinolitic belt at the Michigamme mine, but which had previously escaped my observation, as the limited outcrops of these dark colored mica-schists crowded with red garnet crystals, seen near the track of the H. & Ont. R. R., were considered by me as a subordinate seam of the actinolite-schist belt underlying the limonite-bearing group, as I saw the large body of mica-schists presenting itself almost a mile farther south, seemingly overlying these graphitic and limo-

nitic rocks which actually lie wedged in between a fold of the mica-schists. The northern side of this synclinal fold is hidden under a deep cover of boulder drift, but space enough is left for a wide belt of the schists, as the first indications of the presence of the overlying rock belt are over half a mile south of the exposures of the mica-schist, on the railroad near Michigamme village.

As I intended to retain in this report the stratigraphical order observed in the previous volume, the above description should have been given in the succeeding chapter, but it is sometimes unavoidable to deviate from this plan, if localities have to be described in which an extensive series of rock beds is displayed.

Before proceeding to describe the progress of the examination in the iron districts of Felch Mountain and in the Gogebic Range, I have to mention yet certain peculiar rocks found in association with the iron ore at the Washington, Edwards and Champion mines; at the Spurr mine and Michigamme mine similar rocks are found in large blocks among the loose rock masses covering the surface, but to find them in place there I could not succeed.

The principal compound of these rocks is a dark green colored, large-leaved mineral, with a bright pearly very perfect cleavage in one direction, brittle and of the hardness of feldspar, which I supposed to be hypersthene, but was afterwards informed by Prof. J. D. Dana of its identity with chloritoid, as it perfectly decomposes on treatment with concentrated sulphuric acid, which does not act on hypersthene.

In the eastern pits of the Washington mine and likewise in the Edwards mine an almost black crystalline rock occurs next above the productive ore seam, which consists of an agglomeration of coarse blades of this mineral with a small proportion of reddish feldspar crystals and of hydromica filling the interstices; here and there are also clusters of prisms of black tourmaline and scales of dark green biotite, which latter are also found penetrating the substance of the chloritoid crystals.

This variety of the rock resembles in its structure an eruptive mass, but in intimate association with it are other well laminated schistose beds, in which the chloritoid crystals are distantly scattered, the sedimentary origin of which beds is unquestionable. These schists consist of silvery soft hydromica, copiously mingled with dustlike magnetic granules, in which very much wrinkled

and corrugated groundmass large blades of the chloritoid, more than an inch in length and half as thick, are irregularly imbedded.

This schistose form of the rock is not so common in the Washington and Edwards mines, but it forms a large belt adjoining the ore of the Champion mine.

The loose blocks found south of Michigamme village and on the north side of the railroad between the Michigamme mine and Spurr mine, are quite large, several of them are 10 feet high and 20 or 30 feet long. They consist of a mixture of dark brownish hexagonal biotite blades about one millimeter in diameter with an equal proportion of white hydromica scales and disseminated magnetite granules, in which groundmass lentiform concretions of the chloritoid are distantly imbedded, or locally also larger masses of it are found crowded together. These biconvex lentils, often over two inches wide and in the center three-quarters of an inch thick, have a continuous cleavage, which, if practically possible without breaking them, could be split according to their curved cleavage seams into an inclosed set of disks, like watch glasses; the transverse fracture of the crystalline masses is dull, lineated in the direction of the cleavage.

At the Champion mine, with these chloritoid-bearing hydromica-schists, other rocks with a groundmass of hydromica occur, which at a distance resemble a coarse-grained variety of the above mentioned groundmass of the loose blocks holding chloritoid, but the biotite blades in that are, in this rock, represented by small reddish brown colored, semi-transparent, tabular orthoclase crystals.

(B) MENOMINEE REGION. 1. FELCH MOUNTAIN RANGE.

In regard to the iron-bearing rock series of the Quinnesec Range, I have nothing of importance to add to the previously given descriptions.

Explorations on the range were constantly going on and have led to the discovery of some new localities promising to be valuable for mining. On the other hand some of the older mines became exhausted, and probably more of them for that reason will have to be abandoned, if meanwhile no new deposits should be found besides those presently in sight.

The great anticipations of inexhaustible ore deposits in the

Felch Mountain district have likewise not been fully realized, although some of the opened mines promise well.

From the former descriptions I gave, it will be remembered that the strata of the iron-bearing group in the Felch Mountain Range dip under a high angle northward and consist of the following succession of beds:

The underlying rock of the iron ore formation is always formed of crystalline rocks, granite or diorite. The lowest strata are generally heavy, light colored quartzite beds, with interlaminated thinner ledges and schistose seams, amounting to considerable thickness.

Above this belt an equally large succession of well-laminated, even-bedded, often fissile, slate-like micaceous quartz-schists follow, which have a great silvery lustre. Next above them comes a series of micaceous argillites amounting to a belt even larger than the former, which varies greatly in shades of color, firmness of grain, etc.; some layers are whitish, others gray or bluish and greenish, but the greatest portion of them is intensely red colored by hematitic pigment. A part is a fatty impalpably fine mass of silky or also pearly lustre, according to the size of the mica scales incorporated with them. Another part is rough and gritty from the prevalence of arenaceous constituents.

At this horizon and rather in the lower part of it occur locally large bodies of crystalline limestone ledges, some snowy white like Italian marble, but of coarser crystalline grain and intermingled with radiating clusters of asbestine fibres and larger prismatic crystals of colorless tremolite, which sometimes forms larger concretionary seams in the lime-rock, and are then intimately associated with crystal masses of sahlite, one mineral penetrating the other in a manner which suggests either a process of paramorphosis in progress, changing the sahlite into tremolite, or the original conditions, when the calcareous material combined with the silica by a slight modification, induced simultaneously the crystallization of the almost identical chemical combinations in one and the other form; which latter suggestion is more sustained by the actual condition of the mingled minerals than the first, as some of the crystals of both minerals tightly grown together are so perfect in form peculiar to each and so sharply defined that they must be considered as crystal individuals which formed side by side and altogether independent

of one another. In other localities where such crystalline limestone belts occur, the tremolite is only sparingly intermingled, but in its place colorless mica scales of nacreous lustre are plentifully disseminated.

In the place of marble-like limestone sometimes also ordinary lime-rock of dull aspect with conchoidal fracture, and variously tinged, occurs; it is then usually full of flinty siliceous seams, resembling the limestones of the Quinnesec range; the quartzose seams locally even prevail over the calcareous. Incumbent on the before mentioned micaceous argillites succeeds a belt, about 800 feet in width, composed of thinly laminated banded ferruginous quartzite ledges of dark purplish tints or having a metallic lustre from intermixture of specular ore granules. The banded portions are formed of an alternation of narrow seams of specular ore with siliceous seams not so richly impregnated with the oxide. Other strata in the succession are porous cherty rocks charged with ochreous yellow or brown oxide of iron and enclosing pockets of the limonitic ore. Also blood-red argillitic seams occur in the succession and with them sometimes pockets of soft crumbly hematite ore.

Within the first mentioned banded alternation of narrow ore seams with quartz seams, larger deposits of specular ore in slaty or in compact granular, or also in the soft friable condition of the so called blue ore of the Quinnesec mines occur, which constitute the principal storage of ore sought for by the miner, besides the hematitic and limonitic deposits mentioned before. The first impression of every observer examining this above described rock series will induce him to consider it as an ascending succession, as the layers follow one another in apparent conformity, but in some localities, after having crossed this succession so far, if we proceed farther in the same direction, we intersect the same series again in an inverted order, but retaining the same dip, until we have reached again a large belt of compact quartzite ledges in close contiguity with granite or also diorite, as it may happen, which latter rocks then form the surface rock of large areas on the north side of the Felch Mountain ore formation. Several localities in which these observations can be made are on the north line of Sec. 31, T. 42, R. 28; likewise in Sec. 31, T. 42, R. 29, and also at the quarter-post of the west line of Sec. 28, T. 42, R. 28. At the latter locality, however, the exposures are interrupted

by horizontal Silurian sandstones resting on the top part of the hills.

The only satisfactory explanation which I can give of this repetition of the rock beds in an inverted order, is the suggestion of a folding of the beds and the overturn of the fold by a pressure acting principally from the north side. If this is the case, we would have to consider the light colored quartzite next to the granite as the most recent deposits and the dark ore-bearing banded quartz beds as the oldest, which would bring the structure of the Felch Mountain ore formation in perfect harmony with that of the Quinnesec ore range.

The limestone described on page 202 of the previous report as occurring interstratified with the banded ore-bearing beds on the slope of the hill near the center of Sec. 31, T. 42, R. 29, is a detached mass wedged in between a fold of the ore-bearing beds during the upheaval and in this way escaping destruction by the erosive forces which swept off the balance of superficial rock masses.

Likewise are the limestones south of the Metropolitan mine, mentioned on page 196, loose outliers, entangled between the ore-bearing beds. These quite large masses are disposed in several parallel rows trending east and west; the position of the ledges is nearly vertical, and no one seeing the outcrops would suspect them to be loose masses, if it was not for the work of the explorers for iron. They dug in various places test-pits into the ferruginous beds at the base of these limestone crests, on one side and finally came out on the other side without ever having touched the limestone, constantly remaining with their tunnels in the iron-bearing beds. Several hundred steps south from there similar limestone masses are found in direct contiguity with granite. Another mass of limestone, most likely also not in place, was struck on the north side of the pits of the Metropolitan mine. During the exploration of the property with the diamond drill, the boring commenced in dark red colored micaceous argillites and from next under them a snow white crystalline limestone came out in the cores. Judging from the quantity of cores left near the drill hole, the belt of limestone must have been very thick.

The ore-bearing formation in T. 41, R. 28, two miles south of Felch Mountain, belongs to the same horizon as the ore beds of

the latter. Natural exposures are not so extensive as there, as the greater part of the surface is covered with drift masses and underlying horizontal Silurian sandstones.

In test-pits opened in Secs. 17 and 18, by Mr. Brotherton and others, the strata dip to the north and follow each other in the same order as on Felch Mountain; farther south are light colored compact quartzites; above them a wide belt of micaceous argillites follows, which are intensely impregnated with hematitic oxide and from time to time interstratified with quartzose beds likewise deeply ore-tinged. North of the argillitic belt the wide series of jasper-banded lean ores succeeds, which, like in other places, locally encloses pockets of the soft crumbly blue ore, also red hematite ore, but none I observed large enough to promise great value to the miner.

Farther north we leave the jasper-banded ore belt, crossing a swampy depression with no exposures in the south part of Secs. 8 and 9, but on the other side of the depression a ridge parallel with the other rises, which is found to be composed of the same iron-bearing strata as the former ridge, but succeeding in an inverted order and dipping to the south. First comes quartzite, beneath it the micaceo-hematitic argillite belt, then follows the large body of jasper-banded lean ores in a much broken corrugated condition. It projects in steep bluffs on the northern brow of the hills, at the base of which red colored ferruginous argillites are denuded in test-pits; still lower in the embankments of a creek, dark green schists come to the surface and across the creek granite bluffs are close by.

Extensive explorations in Secs. 8 and 9 have led to the discovery of rich pockets of the blue ore, but the greatly disturbed, faulted condition of the beds is a great obstacle, preventing a systematic plan in mining and making the extraction of the ore more expensive. This southern ore formation has only been traced for the length of a few miles.

The Felch Mountain Range has been traced east of the Metropolitan mine for five miles, but so far no valuable ore deposits have been found in that direction. Westward the belt has been traced, with some short interruptions, to the Menominee River, north of Badwater village.

On this whole interval, besides the pits already mentioned, many others have been opened which exhibit an immense amount

of low-graded mixed ore, but no large deposits of the better high-graded quality.

In the exploring pits of Mr. Breitung in T. 41, R. 30, N. E. ¼ of S. E. ¼, the succession of beds is as follows: Farthest north, bordering a swamp, a row of bluffs from 15 to 20 feet in height trends across the center of the section from east to west, which consists of nearly vertical ledges of a dark colored quartz-rock banded with seams of bright specular ore in alternation with the quartzose seams; their dip is northward. South and conformably underlying this belt succeeds a large series of sericitic or micaceous schists of silvery luster, red tinged by rich impregnation with iron oxide; farther south crystalline limestones follow full of asbestine fibres and at the same time of pearly shining scales of colorless mica. Interlaminated with the marble-like lime-rock many quartz seams occur, and in a still lower horizon a large body of heavy light-colored quartzite beds terminates the exposures and they project in vertical bluffs near the summit of the ridge, the top of which spreads out into an undulating drift-covered plateau.

According to the previously proposed theory the strata in this locality are in an overturned position, which seems to be most generally the case in the entire range.

2. MENOMINEE AND MICHIGAMME RIVERS.

The iron-bearing rocks found between the mouths of Michigamme and Paint Rivers into the Menominee, on the Wisconsin and on the Michigan side, differ from the Felch Mountain rocks and are of later date, probably contemporaneous with the ores of the Commonwealth mine and those of the Northampton mine in the Michigamme district; perhaps even they might represent the oldest beds of the mica-schist group, which is well developed in the immediate vicinity thereof.

In the N. W. ¼ of Sec. 17, T. 41, R. 31, Mr. Bordman made explorations in these iron-bearing beds. He began to dig test-pits in the large body of micaceous schists interlaminated with quartzose seams, of which I gave a description in a former report. Some of these beds are light colored, gray or greenish, but others are intensely red colored by hematite, so as to resemble a soft hematite ore where this impregnation reached a certain degree, but good real iron ore did not occur in association

with them. He found, however, in the lowest position right on the surface of a superficially decomposed diorite belt underlying these beds, and in clefts of the diorite, pockets of a compact hydrated iron ore, which to all evidences has been a secondary deposit of infiltration a long time after the deposition of this schistose series.

Under entirely similar conditions iron ore occurs on the opposite side of Menominee River at the abandoned Ellwood mines. The ore there also forms an incrustation on the surface of a decomposed, crumby diorite mass and fills crevices in it. The mica-schists exposed at the mouth of Paint River and down stream, which I will specially describe below under the heading of mica-schist formation, are in most intimate stratigraphical and lithological connection with the schists on both mining locations. At the Ellwood mine a part of the schistose beds is graphitic, also otherwise a great similarity of the entire group of beds with the schists exposed in the environs of Keyes Lake is obvious, which latter represents a part of the rock series enclosing the Commonwealth mine ore deposits. Another isolated patch of ferruginous deposits which attracted the explorers in this part is found a short distance below Badwater village in a ravine between two ridges of diorite in the N. E. ¼ of Sec. 31, T. 41, R. 30. It consists of a series of nearly vertical beds of calcareo-actinolitic composition which enclose a large proportion of coarse granules of magnetite of octahedric form. Adjoining the beds are well laminated, dark colored chloritic schists in conformable position with the others, then on both sides of the ravine massive diorite crops out. Considerable work was done to uncover these beds, but no merchantable ore was found, and even if it was, the deposit is too limited to be of value. The age of these actinolite beds I think corresponds with the actinolitic layers of the environs of Keyes Lake, subordinate to the Commonwealth ore formation. To the same geological horizon belong the ore-bearing strata uncovered by explorers on both sides of the Michigamme River north of Lake Mary, in Sec. 5, T. 42, R. 30, and in adjoining sections. There is quite a large succession of micaceo-ferruginous argillite-schists interlaminated with quartzite seams and jaspery banded beds, which enclose concretionary masses of limonitic ore in the form of crystalline grape-ore, and in amorphous, earthy or compact form; these

beds repose in steep inclination on a substratum of diorite, which, in association of granite, is the general surface rock of this part of the country.

Eight miles farther north, in T. 44, R. 31, Secs. 33 and 34, near Michigamme River, Mr. Brotherton made explorations in iron-bearing rocks which correspond in age with the Quinnesec ore range, and cover there quite an extensive area.

In Sec. 33, on the north side of the exploring pits, we find a ridge of schistose and massive diorite which is intersected by dykes of diabase which locally are found in a friable decomposed condition, in which the feldspar became altered into kaolinite and the augite into a rusty, non-transparent mass. In fresh condition the rock is dark, blackish green colored, and under the microscope the plagioclase is transparent, exhibiting polysynthetic striation; the augite is partially altered into a green substance. Next incumbent on the diorite rocks are hydromicaceous and feldspathic schists of light greenish yellow color with blood-red streaks and blotches tinged with hematite. Other streaky portions of these schists are lead-colored by an abundance of octahedric magnetite grains incorporated with the mass. These eminently schistose beds in part resembling novaculite, by segregation of flesh-red orthoclase crystals and of transparent quartz grains, by gradations merge with a massive protogine or granite which underlies these schistose strata.

Above this quite large belt, which dips under an angle of about 60 degrees to the southwest, succeeds a series of dark, purplish blue, ferruginous quartzite beds of metallic lustre, amounting in the aggregate to 400 or 500 feet. The color of the beds is due to their impregnation with specular ore granules, which in certain layers of the series amount to more than half of the weight of the rock, but all were too siliceous to pass for an ore salable in the present iron market.

Next above this large body of lean iron ore, as I may term it, follow light colored, slaty, silico-argillitic and hydromicaceous beds, which also amount to a wide belt; upwards in this succession calcareous seams begin to intermingle until heavy compact limestone beds of pale reddish color finally exclude all the slaty beds and terminate the exposures by forming a separate hill range, totally composed of limestone.

About a mile north of this locality, in Sec. 34, a similar but

somewhat different group of iron-bearing beds is observable. The surface there is to a great extent covered with drift and Silurian sandstone. My observations, therefore, depended principally on an examination of a row of test-pits opened at right angles to the strike of the formation, which is there north and south, the dip west. Commencing on the east side, the first test-pits have uncovered red colored micaceous argillites in harder and softer slaty layers, in the next ones quartzite beds intersected with irregular seams of a steel-gray siliceous iron ore can be seen, then follow others dug into a belt of micaceous argillites, and next another large belt of quartzite of light color succeeds, then come quartzose hydromica-schists, partly dark blackish, partly light colored, which are interstratified with ledges of limestone. The beds are no further denuded.

A half mile northwest of this place, in Sec. 28, in the embankments of Michigamme River, and likewise lower down stream in Sec. 32, large exposures of a red colored, compact limestone interstratified with slaty seams occur; the limestone belt is several hundred feet in thickness. In the adjoining bluffs on the north side are seen denuded quartz-schists, banded with ore seams and slaty rock beds, their beds dipping in conformable steep inclination under the limestone.

From here northward unto the Republic mine I did not examine. From reports of explorers I learn that on this interval in many places the ore-bearing series forms the surface rock, but deposits of iron ore, being valuable, have not been discovered by them.

(C) GOGEBIC REGION.

It remains for me to report on another iron district which recently has attracted much attention of the mining and speculating public; this is the country environing Lake Gogebic.

The occurrence of iron-bearing rocks in the Gogebic country was first made known by the linear government surveyors, who indicated the localities on the town maps where iron ore was found by them. During the progress of the present geological survey Major Brooks and Professor Pumpelly went over that ground and gave a short description of the geological features of it in the first volume of the Michigan Geological Reports. Then scarcely any mining explorations for iron had been commenced

there, but shortly after, the Gogebic iron range and its continuation, the Penokee range in Wisconsin, became the favorite resort of iron-hunters.

Since then a large amount of labor and capital has been and is yet spent there in explorations, partly with success, partly leading to disappointment, which is not otherwise to be expected.

The eastern portion of the range, extending from Lake Gogebic to the Montreal River across the center part of the ranges 44, 45, 46 and 47, of the town tier 47, did not prove to be much charged with iron ore to the east side of Sunday Lake (more recently, after I examined this region, also east of Sunday Lake, iron was discovered, but as it appears, not in paying quantities), but west of it unto Montreal River it was found to be richer and in a number of localities iron ore of very good quality and in paying quantities is so far demonstrated to be present, but no actual mine has been opened yet, as these remote places must first be brought into communication with the outside world by the construction of a railroad, which is surveyed but only partially built at this time.

My own observations in that district which I am going to describe depended in a great measure from the work of the explorers, as natural exposures are very limited in these unbroken forest lands, and many of those existing escape the attention of a transient traveler who usually cannot see many rods beyond the spot he stands on. On this occasion I also express my thanks for the many favors I received from these kind-hearted woodsmen while I was among them, and without whose help I could not have accomplished much.

Examining the general geological structure of the country surrounding Lake Gogebic, we find the entire circumference of the lake formed by sand beaches or terraces of boulder drift; the boulders are of large size and are in the great majority derived from the Keweenawan group, consisting of various modifications of red porphyry and of melaphyr and amygdaloid rocks; a smaller proportion is granitic-gneissoid and dioritic. Not a great distance off from the shore on the north side and the north half of the west side of the lake, the rock walls of the Keweenawan diabases begin to rise successively into hills from 200 to 500 feet in elevation.

The iron-bearing Huronian rock belt from the direction of its

trend should be expected to strike the west side of the lake in its south half, but no outcrops of it are seen nearer to the lake than a mile or two from it.

Only at the extreme end of the lake, where a river enters it, bold bluffs of rock about 60 or 70 feet high rise directly from the edge of the water; they are hard schistose or slaty beds dipping under a steep angle southward; their composition is a minutely granular feldspathic groundmass in intimate intermixture with mica scales of great delicacy, which impart a silky lustre to the dark gray colored ledges.

This slaty rock is found to compose all the surrounding hills in the background and to form a belt several thousand feet in thickness. Following the river from the inlet upward, it has for two miles a very sluggish, meandering course, bordered by low marsh lands. At its junction with several tributary creeks, the ground rises and the hills come close up to the streams, which, in their narrow ravine-like valleys, have a swift current and in their descent over the denuded edges of the slate-rock formation on the steeper parts of the hills form numerous low cascades. The endless succession of slaty strata visible in the beds of these creeks varies some in grain, color and hardness, but the entire complex has one common general character in its structure and composition, by which the members belonging to this belt are, without difficulty, distinguished from other rock formations coming in contact with them in this vicinity.

I followed the principal branch of the river from its union with the other branches, in its narrow bed bordered by steep bluffs of the slate-rock, to the quarter-post on the south line of Sec. 16, then went on the section line as far as to the southwest corner of Sec. 14, returning diagonally across Sec. 15 to the S. W. ¼ of Sec. 9, where I had my camp.

With the exception of a belt of dioritic outcrops on the line between Secs. 14 and 15, all the surface rock I could see on this circuit walk belonged to the slate formation, and the dip of the strata regularly was directed southward. The Government surveyors have noted on the town maps the occurrence of a belt of iron ore near the center of Sec. 15, but my attempts to find this outcrop were not successful. The dioritic rock belt before mentioned is at the surface there in contact with the micaceous schists, but the ore seam I could not discover.

Wishing to examine the rock formations south of this area formed of slate-rock, I accepted the invitation of an explorer to accompany him to Sec. 35, T. 46, R. 43, where he pretended to have found a gold-bearing quartz vein intersecting the granite. The trail he led me went through almost impenetrable brushes of ground-hemlock (Taxus Canadensis) in alternation with spacious marsh grounds, where acrobatic dexterity was required to walk the slender poles laid across the bottomless mud holes; finally he showed me, in the midst of an alder bush swamp, a few knobs of granite associated with hornblende rock of laminated gneissoid structure, emerging only a few feet above the general level, which rocks were intersected by a narrow vein of milky quartz containing small, thinly scattered concretionary masses of iron and copper pyrites, so little promising in appearance that even in case the pyrites were auriferous, which I positively doubt, the poverty of the quartz vein in the pyritous minerals would preclude all expectations to mine with the slightest hope of success. After a short rest from this tiresome walk we took our back tracks, both disgusted, the explorer because I would not believe in the value of his discovery, and myself for having seen so little of the structure of the country over which I had to travel with so much exertion, as after we left the mica-schists exposed in the creek bed in Sec. 21, no more outcrops of any kind of rock could be seen along our path until we came to the aforesaid patches of granite.

A year afterwards I came again to the southward of Gogebic Lake, accompanied by Mr. P. Mitchell of Ontonagon, who, carefully searching for the ore belt noted on the maps of the surveyors, finally succeeded to find such a belt trending from east to west across the north part of Sec. 13, T. 46, R. 42, and was presently at work to test its value by sinking a row of pits transverse to the stratification.

The strata dip south under a high angle in conformity with the overlying mica-schist formation before described as being the prevailing surface rock in the surrounding country. In the pits an almost uninterrupted cross-section through about 800 feet of strata is laid open.

Farthest north a large body of partly massive, partly schistose dioritic rock projects in bluffs along the slope of the hills; conformably resting on these succeeds a series of dark lead-colored, silky, shining, fine-grained and very even-bedded slaty rock beds

of micaceo-feldspathic composition, about 100 feet in thickness; then follows a banded alternation of similar schistose material, with quartz seams amounting to nearly the double thickness of the former, which beds are in a considerably twisted corrugated condition. The thinly laminated alternating seams are from time to time interposed with large lenticular, flinty quartz masses and locally, instead of being corrugated, the rock seams are fractured and recemented into a breccia. South of this series lead-colored, even-bedded micaceous slate-rock layers similar to those lowest in the section, set in again in great force; they are copiously disseminated with magnetic granules as also the banded rock series below them locally was. Within these upper magnetite-bearing micaceous schists are interlaminated larger and smaller belts of banded magnetic ore, the bulk of which consists of about one half of its weight magnetite, the other half quartz grains and mica scales; the richer seams of the banded ore mass on analysis yield about 11.5 per cent of insoluble residue, 56.3 per cent of metallic iron, 5.7 per cent of carbonate of lime and magnesia, and an unusually large proportion of phosphoric acid, amounting to 1.38 per cent. South of the test-pits furnishing the siliceous ore, succeeds a large series of quartziferous actinolite-schists containing an abundance of octahedric crystals of magnetite; interstratified with them are dark green biotitic and chloritic schists which enclose locally a large number of garnet crystals, varying in size from that of a pea to that of a small hickory nut; also seams of magnetic ore are found within them. Then another succession of smooth-bedded, lead-colored mica-schists is met with by going south across the formation. Beyond them, after traversing a covered space, we find a dioritic rock belt similar to the one on the north side of the described section. All the surface rock south of this diorite belt is formed by the mica-schists which I have previously considered as analogous with the mica-schist formation of the Michigamme region.

The direct superposition of these mica-schists and the general lithological character of the strata enclosing the iron ore seams induce me to suggest their identity with the ore-banded actinolite formation overlying the magnetic ores of the Michigamme mine, and particularly with the ore-bearing series of rocks at the Magnetic mine.

The iron-bearing strata of the range extending from the center

of the west side of Lake Gogebic towards Penokee Gap, differ in many respects from the just described group, but nevertheless I think to have sufficient reason to consider them as representative of the same geological horizon and as younger than the Marquette and Felch Mountain ore deposits.

The ore-bearing strata displayed in the Menominee region, on the north side of the Quinnesec ore range, are in all probability a perfect counterpart to them. Here as well as there a large belt of limestone forms the base of the series; the ore in both localities is, to a great extent, limonitic ore; in both places are graphitic schists associated with the ore deposits, and in the Penokee region the immediate succession of the mica-schist formation above the ore formation, is a further indication of the younger age of this group.

The following detailed description of the Gogebic iron range will enable the reader to judge for himself whether the proposed suggestion is admissible or not.

Starting from the landing on the west shore of Gogebic Lake, situated in the center of Sec. 17, T. 47, R. 42, on an old Indian trail, we meet for the first two miles no rock exposures, thence repeatedly in the hillsides, to the left of the path, bluffs of rock are seen to project which, on examination, are either granite or the brecciated diorite rock mentioned in the previous chapter; farther on, quartzite beds are seen to underlie the surface on the right hand side of the trail as we approach the mining camp of Mr. Gillis, situated in the southwest quarter of Sec. 14, T. 47, R. 43, where, by natural and artificial denudation, we are enabled to see a cross-section of about 800 or 900 feet of strata which dip under a high angle to the north. The aforesaid brecciated dioritic schists are seen in the hillside south of the camp, as the lowest; on them succeeds a belt of dark comglomerate, composed of quartz pebbles of various colors and of granite pebbles, cemented by an arenaceous groundmass holding a considerable amount of feldspar grains besides the quartz sand. Then follow thick-bedded gray quartzite layers; on them rests a flesh-red colored, compact granular quartz belt, which, by exposure, weathers and becomes porous, absorbent, like an ordinary sandstone.

Higher still are brecciated quartzite layers composed partly of chalcedonic quartz masses and intersected by irregular fissure seams filled with galena.

On this brecciated quartzite belt follow thinly laminated quartz layers of very uneven surface with interposed narrow wedgelike seams of black shaly material which causes rapid disintegration of this belt into shelly fragments. Within this series occur streaky interrupted concretionary seams, parallel with the stratification, which are filled with galena. Higher beds, likewise mainly of quartzose nature, are even-bedded, delicately striped or lineated in the direction of the bedding by the alternating intermixture of linear graphitic seams with the granular quartzose feldspathic groundmass, which besides holds a good proportion of the carbonates of lime and of iron; weathered surfaces of the white and black striped rock are therefore rusty brown. In some of these layers the shaly graphitic material predominates over the quartzose, which causes them to be softer, more pliable; the upheaving pressure therefore folded them throughout their substance into innumerable small wrinkles, as we often observe the same phenomenon of corrugation in the still softer sericitic or micaceous schists in other geological horizons. North of these beds follow uniformly black, fine-grained, slate-rock layers, which are from time to time interlaminated with seams of harder siliceous ledges likewise black colored by carbon; the aggregate thickness of this uppermost graphitic slate-rock belt amounts to about 500 or 600 feet. It comes, on the north side, in direct contact with the diabases of the copper-bearing rock group, which appear to be conformably superimposed on it.

The galena, according to several samples analyzed by me, contains only a small proportion of silver, too little to work the mine for its value in silver, and for the lead alone, I think, the supply of ore obtainable would be too small.

This galena-bearing quartz formation and the graphitic slate series above it are traceable by extensive exposures in the hillside along the trail, until it crosses Presque Isle River in the S. E. ¼ of Sec. 17, the bed of which is carved there diagonally across the stratification into the black graphitic slates, amounting also there to a very thick succession of beds.

A mile farther west, in the S. E. ¼ of Sec. 18, T. 47, R. 43, I met, for the first time, with outcrops of dark purple colored, banded quartzite beds formed of alternating seams, some of them richly impregnated with specular ore grains, and others of a more purely quartzose composition; the rock belt to which these strata

belong, is exposed in the bed of a small creek, but the exposures are too limited to offer a cross-section giving information of the thickness of this belt and of the rock adjoining it, but as the trend and dip of the beds are in conformity with the graphite-slates and the galena-bearing quartzites, it is probable that they belong approximately to the same geological horizon. West of this creek, the trail follows the south line of Sec. 18, and then of 13 and 14 in the adjoining township, into Little Presque Isle River, a side-arm of the other. The ferruginous quartzites trend westward some distance north of the trail, which passes over dioritic rocks for all this distance.

I have in the previous chapter mentioned the generally fine-grained quality and light color of these rocks, and the occurrence of schistose brecciated belts in association with the massive. High bluffs of these breccias border the east side of Little Presque Isle River, from the top of which the rare opportunity of an extensive panoramic view to the west and south offers itself, which, after many days confinement within dense forests, restricting one's vision to the distance of a few rods, is a great relief, wonderfully invigorating the spirits suppressed by the former monotony and the connected fatigue of the travel.

West of Little Presque Isle River, which here coils its flow into the most intricate curvatures, very perplexing for a stranger not informed where to cross the marshy valley, densely covered with willows and alder bushes for several miles; no rock exposures are visible alongside the trail. Approaching the southeast corner of Sec. 17, T. 47, R. 44, compact light colored quartzite beds form the surface rock and project sometimes in a row of bluffs; further proceeding, we find on the left side of the trail, across the south part of Sec. 17, a rocky hill range of considerable elevation trending westward, which is composed of a large succession of siliceous limestone beds, dipping under a steep angle northwest. South of the limestone, dark colored schistose quartz-rocks of granular structure with an interstitial hydromicaceous and partly chloritic cement, are the underlying rock beds. The structure of the limestones with interlaminated siliceous seams and the corrugations of the beds correspond entirely with the limestones connected with the ore-bearing beds of the Menominee district. On the west line of Sec. 17, the trail we followed turns northward, diagonally across Sec. 18, and thence leads

through the north half of Sec. 13, T. 47, R. 45, to the southeast corner of Sec. 11, where Mr. Gillis had erected another exploring camp. All the exposures we met with on this path were quartz-rocks, whitish or reddish colored, and at times some slaty rock-layers were found, interlaminated with the quartz beds.

Near the camp are good natural exposures, and the test-pits of the explorers had pretty thoroughly uncovered the beds in the intervening spaces, so that quite a large series of rocks could be observed here in an uninterrupted cross-section by correlation of the different openings.

Commencing the examination near the southeast corner of Sec. 11, we observe the following succession of beds: At the base of the south slope of the hill range on which the corner is located we find thick-bedded, compact, light colored quartzites dipping under a steep angle to the north; above them conformably follows a series of brecciated quartzrock beds, consisting of a well laminated fine-grained, somewhat porous cherty groundmass, more or less impregnated with hydromicaceous scales, drab colored and blotched with irregular red spots, which encloses numerous angular quartz fragments, some with glassy fracture, others of the nature of a brownish chalcedony; the thickness of the brecciated belt amounts to about 30 or 40 feet.

It is succeeded, upward, by a very large alternation of thin-bedded siliceous flagstones, with slaty layers changing in all shades of colors, gray, brown, red, greenish, and all with some degree of sericitic lustre.

The summit part of the hill range and all its north side are formed by these beds, amounting to an aggregate thickness of from 400 to 500 feet. Further north the exposures are for some distance interrupted by the swampy bed of a creek, but on its north side the strata are again uncovered by the exploring pits, after removal of about 12 or 15 feet of drift from their surface. They consist of a large succession of well laminated, very even-bedded, almost black colored fine-grained siliceous schists banded by the alternation of seams more richly impregnated with magnetic ore granules than the intervening ones. The black color appears to be in part due to graphitic or carbonaceous material, intimately mingled with the rock substance, and not to depend exclusively from the magnetite incorporated with it. Seams purely composed of magnetic ore are not found. This belt of

magnetic schists is 1,200 feet north of the section line from which we started in the examination of this locality; it has a thickness of several hundred feet and is seen on the higher part of the hill slope in close contact with an overlying diabase belt of the cupriferous formation, which, farther north, other partly amygdaloidal, partly porphyritic diabase belts follow.

The contact of the magnetic schists with the diabase belt is to all appearances conformable. A mile west of this place are numerous other exploring pits opened, a part in the N. W. ¼ of the S. W. ¼ of Sec. 10, another in the N. E. ¼ of the S. E. ¼ of Sec. 9.

There was discerned a succession of about 500 feet of red colored banded jaspery beds, with likewise red colored slaty seams interstratified, which softer slaty beds locally were so rich in hematite iron oxide, as to be with difficulty distinguishable from the hematitic ore deposits, of which lenticular seams, widening at times into larger pockets, were found in the same association of rock beds; besides these soft paintlike hematite ores, occur also pockets of a harder, compact hematite ore.

Some of these ore deposits promise to be large enough to have value for the miner. A difficulty in mining them would be to prevent the mixture of the ore with the surrounding shattered, brittle, siliceous rock beds, scarcely differing in color from the ore.

An analysis of the soft kind of hematite showed in one specimen 91.4 per cent oxide, 6.66 insoluble residue; another held only 70 per cent of the oxide and 27.2 per cent of insoluble residue of argillaceous nature. The amount of phosphorus in both specimens is small.

This series of red colored hematitic rocks is, on the north side, in direct contiguity with diabases of the Copper-bearing formation. No equivalent of the magnetic schist forming the contact line in the other locality is noticeable here, but south of the test-pits, after passing over a covered space about 300 or 400 feet wide, we find the continuation of the hill range from which in the former place we started in the description of a cross-section. Most likely therefore the dark colored magnetic schists would be found in this covered interval between the hematite pits and said hills.

In this locality a great difference in the angle of inclination of the strata is observable; the beds closest to the diabase stand

almost vertical, while those in the test-pits farthest south have a dip of only thirty or forty degrees to the north.

Not a great ways west of the test-pits we find Sunday Lake, on the other end of which we come to other exploring pits for iron, in Sec. 7, T. 47, R. 45. On the maps of the Government surveyors a row of hills crossing the south part of this section is marked as consisting of iron ore, which is in reality a large belt of the magnetic schists analogous with those found in the test-pits in Sec. 11, as before described.

These dark, blackish colored, slaty rocks, interlaminated with belts of compact quartzite, like the slate impregnated with magnetic granules, amount to 400 or 500 feet in thickness; their dip is north, under a high angle, and on the north side they are conformably succeeded by an equally large succession of red colored, jaspery beds in banded alternation with seams of more or less siliceous red oxide, just the same series as we found in the pits on the east side of Sunday Lake. The upper horizons of this group of beds are much richer in iron ore than the lower, but so far no profitably workable deposits have been discovered in this locality. We find here again the copper traps in conformable contact with the ore-bearing series.

While unto here all the explorations for iron promised to be most successful in the upper horizons of the formation, above the belt of dark magnetic schists the exploring work farther west is principally confined to the lower part of the series beneath the magnetic schists.

The exploring pits found in that direction are therefore situated about one mile south of the South Trap Range, following the northern slope of a granite range which trends parallel with the northern trap ranges.

The first of these exploring pits we meet with are in the S. W. ¼ of the N. W. ¼ of Sec. 13, T. 47, R. 46. In close contact with the granite, which forms there the summit part of the hills, we find a light colored, porous, gritty, silico-argillitic rock in rather compact masses, showing little of bedding. Above it follows a great succession of alternating beds of quartzite and slaty or shaly seams, which are all more or less impregnated with brown or also red oxide of iron, and besides inclose irregular seams and pockets of clean ore substance.

Of the quartz beds, some are light colored and thick, but the

majority are thin or flaggy, or form a banded alternation of dark colored, ferruginous and of lighter, purely quartzose seams, which ferruginous bands, parallel with the formation, are connected by cross-fissures filled with limonitic ore, which crevices expand sometimes into larger pockets. This proves the secondary infiltration of the greater portion of the iron oxide. In connection with the dark, red colored, slaty beds occur seams of soft, blood-red hematite. The harder ore filling the crevices between the quartzite layers is dark purplish brown colored, of fine-grained, dull, earthy fracture, but part of it has the radiated crystalline structure of the so called grape ore, and also non-hydrated red oxide is mingled with the ore masses, which gives them a purplish hue. From here to the west end of the state an uninterrupted chain of granite hills extends and continues into Wisconsin after crossing Montreal River.

Everywhere on the north side of this range the iron-bearing rock group is found. The prospects for large bodies of ore are not very favorable in Sec. 13; much better is the show in the test-pits opened in Secs. 15 and 16, under the supervision of Capt. Moore of Ashland, and of Capt. Pease of the same city. Their pits are opened below the edge of the plateau-like hilltops from which, a number of years ago, by a tornado, all the timber was blown down and subsequently was destroyed by fire. At these localities, therefore, a splendid free view is opened in all directions, and particularly northward unto Lake Superior.

The ore deposits here are secondary accumulations in the crevices of a quartzite formation, interlaminated with slaty argillitic rock beds, the total thickness of which series is near a thousand feet. The lower portion of this rock series consists of light colored, slaty beds, which repose on diorite or granite. Next above them, thick, massive, light colored quartzite ledges follow in great force, then a more thinly laminated series of quartz beds succeed, alternately interstratified with slaty argillites. Most of these beds are intensely red or reddish brown colored, or lighter and darker colored seams follow in regular alternation; sometimes a belt of argillites is also fancifully speckled with white and red dots. Within this series, in three or four different horizons, seams of hard, partly limonitic, partly non-hydrated iron oxide have been discovered, which locally change from the width of three and four feet to that of eighteen and twenty. The great bulk of

this ore is an almost aphanitic, fine-grained, compact, bluish, dark colored mass with smooth, conchoidal fracture, giving a purplish brown powder, as it consists of a mixture of hydrated and non-hydrated oxide. The aphanitic substance is permeated with an abundance of radiated concretions of grape ore, giving a powder of light yellowish brown color, but a part of such radiated crystalline concretions consists also of regular hematite, giving a bright red powder, and in the same form also pyrolusite is a very common associate of the iron-ore. Where druse cavities exist the grape ore and the pyrolusite often occur in stalactitic form. On the west side of Mr. Moore's explorations, Mr. Pease opened in the N. E. $\frac{1}{4}$ of Sec. 16 a row of trenches 700 feet long, within the upper thinly laminated banded beds of the series, and laid bare a belt of crumby, partly limonitic, partly hematitic ores, enclosing numerous nodular concretions of pyrolusite, which averages 22 feet in width.

An analysis of a piece of the compact aphanitic ore from Mr. Moore's test pits, gave the following result:

Loss by ignition, 5.2 per cent water.
Insoluble residue, 2.9 per cent.
Oxide of iron, 91.9 " "
Phosphoric acid, small amount, not weighed.

Another specimen of blackish steel-color, with flinty fracture, gave

Water, 2.5 per cent.
Insoluble residue, 1.36 " "
Oxide of iron, 74. " "
Manganic oxide, 16.7 " "
Phosphoric acid, small quantity, not weighed.

A specimen of compact ore, mingled with grape ore bunches, gave

Water, 6.16 per cent.
Insoluble residue, 1.8 " "
Oxide of iron, 90. " "

The soft, crumby ore from Mr. Pease's mine gave

Siliceous residue, 2. per cent.
Oxide of iron, 94. " "
Oxide of manganese, 2. " "
Phosphoric acid, small quantity.

Explorations in the same complex of rock beds were in progress farther west, in Secs. 17 and 18, all having the success of meeting with similar ore deposits, some of them promising to be of value.

In the next western township, N. E. ¼, Sec. 24, T. 47, R. 47, I passed exploring pits in which a belt of dark colored, blackish, soft, crumby ore, about four feet wide was laid open, which enclosed a large quantity of concretions of pyrolusite in radiated bunches of brightly shining prisms. Heavy, light colored quartzite beds form the foot wall of this ore seam, and beneath them a large succession of light colored, siliceous, argillitic slate-rocks is exposed. North of the ore seam red colored, banded jaspery layers are exposed in association with very even ferruginous beds, of metallic luster by rich impregnation with specular ore granules. These are fissile into thin, large slabs, which have been put into use by some of the explorers to cover their huts, for which purpose they answer admirably well. On the north side of these flagstones, a large succession of black graphitic slates follow conformably in this and other localities farther west. On Michigan territory, the last exploring pits for iron are found close to the S. E. ¼ of Sec. 22; the work is superintended by Mr. Wood. The work in that place, at the time of my visit, had not far advanced, but from all I could observe, the strata containing iron ore seams were about the same as in the previously examined localities. Bluffs of granite projected on the south side of the test-pits, no farther off than sixty feet. In the bed of Montreal River, next above the mining camp, a singular, dark colored belt of a breccia crosses the river, which consists of angular, flinty quartz fragments, embedded within a crystalline groundmass formed of carbonate of lime, iron and magnesia; weathered portions of the rock were transformed into a soft, ochreous brown substance, or also having the red color of hematite. On the north side of this quite broad belt ferruginous quartzite beds were exposed, corresponding in appearance with the ordinary layers making part of the iron-bearing series. On the south side, the breccia came in contact with a large belt of diabase, and further south the granite was surface rock. The diabase accurately resembles the diabase rock intersecting in dykes the rocks in the vicinity of Marquette, as for instance, the diabase belt on which the Marquette lighthouse is erected. Under the microscope, its components are transparent prisms of plagioclase and pale brownish augite crystals in about equal proportions, with the addition of a good number of scattered groups of transparent, almost colorless olivine grains intersected by a network of

seams in which minute magnetic granules are crowded together. The circumference of the clusters of olivine grains is also usually dark green colored by infiltration of viridite.

(D) PENOKEE-GOGEBIC REGION, WISCONSIN.

From the Montreal River I followed the iron-bearing rock belt into Wisconsin, which was the shortest way to get out of the woods and more instructive than my return by the same way I came would have been. Crossing Gogogashung River at the south end of an island the river incloses, I had an excellent opportunty to see a very large succession of beds representing the lower horizons of the iron-bearing rock series, as the river had carved its channels across this group of beds. It rushes over them in rapids and a number of smaller cascades, in both of the arms enclosing the island, while above the island a large body of underlying schistose dioritic rocks form the bed of the river. The schists above the diorite form well laminated, even and compact beds of slatelike fissility; their colors are rather light, varying in all shades from gray to greenish, bluish, reddish, brownish; they consist of a fine-grained, silico-feldspathic mass, charged with a greater or smaller proportion of minute mica scales; from time to time coarser arenaceous seams mingle in between the fine-grained, slaty laminæ. The aggregate thickness of this belt amounts to about 300 feet; the dip of the strata is north, under an angle of about fifty degrees. Reposing on them is a series of quartzite beds partly in thick layers, but most of them thin, flaggy and in alternation with softer argillitic seams. All these beds are more or less impregnated with oxide of iron, either merely as a pigment or also as larger concretionary seams of iron ore, limonitic or hematitic. These ore accumulations occur principally in a part of the belt in which the ledges are found shattered into small, angular fragments, and recemented into breccia by these infiltrated ore masses, which, however, accumulated also in the not so much shattered portion of the quartzrock series. What succeeds north of this belt I have not examined, as an accurate geological description of the environs of this place is given in the reports of the Wisconsin Geological Survey.

Two miles farther west, in the north half of Sec. 33, T. 46, R. 2 E., Wisconsin, explorers have opened a large number of

test-pits and longer trenches across the stratification. In these we see farthest south, next to granite bluffs, the same light colored slate-rock series which forms the river bed of Gogogashung River, in the circumference of the island. Above the slates, thick-bedded, light colored quartzite layers and then more thinly laminated, jaspery beds of reddish or brownish color follow. Within this rather wide belt of quartzose beds, irregular seams of iron ore, parallel to the stratification and in transverse seams and pockets, have been laid open, of which some promise to be valuable. This ore is a compact, fine-grained, aphanitic mass of purplish black color, with a smooth, flinty fracture, and in association with it concretions of grape ore are of frequent occurrence.

An analysis of the aphanitic compact ore in one sample gave

Iron oxide,	90.	per cent.
Quartzose residue,	5.	" "
Water,	1.4	" "

Another specimen analyzed gave

Iron oxide,	93.8	per cent.
Siliceous residue,	4.34	" "
Loss by ignition,	1.106	" "

The amount of phosphoric acid in both samples was not great.

North of this group of ore-bearing quartzite strata a broad belt is formed of red colored, banded, jaspery beds in alternation with likewise intensely red colored, slaty argillites, which strata locally also inclose seams of soft hematite ore, some of them three or four feet in width. Next above this group follows a belt of the previously described dark colored, ferrugineo-siliceous banded layers, with bright metallic lustre on the bedding planes, which can be split into thin, even slabs of several feet square and not over half an inch thick; they emit a loud, ringing sound under the stroke of a hammer. Thence farther to the north, a large succession of black graphitic slate-rocks can be traced, until the rock exposures disappear altogether in marshy lowlands, beyond which, at no great distance, the trappean hills are seen to rise.

From here to Penokee Gap, a distance of twenty miles, I had to travel in a constant pouring rain, which prevented me from closer examination of this strip of land, which, by its extensive rock exposures and the regularity of their disposition, is the

most interesting of all that I had seen on the entire range from Gogebic Lake.

The path led me along high rock walls of light colored limestone ledges and quartzite beds, dipping in steep inclination northward, which were succeeded on the north side by a broad belt of light colored silico-feldspathic slate-rocks, on which rested conformably a considerably thick series of dark colored, banded ferruginous rock beds, with bright metallic lustre on the bedding planes, which were formed of an alternation of thin, even seams, almost totally composed of specular ore granules, with others, in which quartz grains, red-tinged by hematitic pigment, prevailed much over the grains of ore in the mixture. In this belt, most tempting by its appearance as a repository of larger masses of pure ore, as I passed along it I found the explorers had spent a great amount of time and labor, but their efforts seemed to be nowhere rewarded, as the large excavations made by them were all abandoned, and no appreciable quantity of high-graded ore masses could be seen amongst the large burrows of rock thrown out of the drifts and shafts, which rock, taken in its totality as the belt furnishes it, contains almost half of its weight in granular martite. A most complete natural section across the iron-bearing rock series, from the granite at its base up to the top part of the Huronian series, and continued across the overlying porphyritic and diabasic rock belts of the Copper-bearing formation, is presented by the channel of Bad River, at and north of Penokee Gap, which cross-section is described in detail by the geological reports of Wisconsin, to which I refer the reader. Comparing this section with the succession of beds on the east side of Montreal River, a general correspondence is observable, but also considerable local differences in the development of the strata are obvious. The limestone belt forming at the Gap the lowest member of the formation and composing rock walls conspicuous all along to the vicinity of Montreal River almost disappears on its east side in Michigan; only in the south part of Sec. 17, T. 47, R. 44, a larger body of the very siliceous limestone ledges shows itself at the surface. The next succeeding rock belt, composed of light colored silico-feldspathic slates, is traceable to the east side of Sunday Lake. The ore-bearing beds are at the Gap represented by dark colored magnetic actinolite-schists. Of the red hematite-bearing jaspery rock series and of the underlying

quartzrock beds intersected by seams of compact limonitic and hematitic ore, which in more eastern localities occupy a place next above the before mentioned light colored schists, nothing is exposed at the Gap; the even-bedded, banded, specular, lean ore belt of metallic lustre, which follows the east side of Montreal River on the north side of the jaspery hematitic series, is here the only representative of this horizon near the Gap. North of it follows a very large succession of dark, blackish colored slate-rocks, interlaminated with brittle, flinty, siliceous rock masses and locally intersected by dioritic belts which seem to be intrusive, which dark slate-rock series is everywhere traceable as far as Lake Gogebic, constituting the upper horizon of the iron-bearing series.

The large belt of magnetic schists in the vicinity of Sunday Lake seems to be its analogon, but anomalous is the occurrence of a large succession of jasper and slate beds, impregnated with hematitic oxide and carrying deposits of hematite ore, on the north side of this belt, as we find it near Sunday Lake. It is therefore possible these dark magnetite-bearing schists might not be the equivalent of the black slates on top of the formation near the Gap and near the Montreal River; but the equivalency of the latter with the large belt of graphitic slates intersected by the Presque Isle River, and east of it, near Mr. McGillis's test-pits for galena, appears to be unquestionable.

(E) VERMILLION RANGE, MINNESOTA.

While engaged on the frontiers of the State, I received an invitation to visit the lately opened iron mines on Vermillion Lake, in Minnesota, which I gladly accepted, as the ore deposits of that region were reported to exceed in size and quality any of the other ore deposits of the Lake Superior district, and to occur in a series of rocks analogous with those associated with the ore in the Marquette region.

A railroad sixty-seven miles long, built from Agate Harbor to the mines, brought me there within a few hours, which travel to the mine, a while before, could scarcely be accomplished in a week under great exertions.

The hills on which the mines are located border the south shore of the eastern part of Lake Vermillion; their trend is from southwest to northeast; their elevation above the surrounding country

is not over 200 feet, and the level of the railroad track at the mines is 800 feet above Lake Superior. The strata composing the hills stand almost vertical; their dip is generally northward, where it can be determined.

Commencing the examination of the rock series on the south side of the mining location, we meet first with a wide belt of light colored gray or greenish or bluish colored hydromica-schists, with interlaminated quartzose seams. Some layers of the schists have a bright satin lustre; in others the lustre is only faint. In the aggregate, the visible portion of this belt amounts to 400 or 500 feet; its north side joins a belt of iron ore from ten to fifteen feet in width. The ore is compact, fine-grained, almost aphanitic, with smooth, conchoidal fracture, of dark purplish, steel-gray color. Occasionally granular-crystalline or radiated-fibrous, concretionary portions are intermingled with the compact masses. On the north side this ore seam is succeeded by other hydromica-schists, more argillitic than the former, some layers intensely red colored or variegated by alternation of irregular whitish and red blotches, much resembling the so called soapstone of the Negaunee mines.

North of this comes another belt of compact ore, much larger than the former but resembling it in quality. In places, the width of this ore belt is sixty feet, and rarely it shrinks down to less than thirty feet, in the trenches by which this belt is laid open for the length of nearly a mile. Its north side is joined by a belt of jasper-banded mixed ore, a regular fac simile of the red, jasper-banded, lean ore belts in the mines of Negaunee and Ishpeming; like there, also here, these banded layers are locally bent and twisted into zigzag plications. Between the regular alternation of thin red or purplish colored jasper seams, with equally thin seams of compact ore, more or less siliceous are, from time to time, bulkier, lenticular masses of clean ore wedge-wise. North of this mixed ore belt follow again hydromica-schists of light color, more compact than the former, a granular ground-mass of feldspar composition intermingled with glassy quartz grains prevailing in them over the hydromica. The greater portion of this large rock belt is twisted into corrugations, or often also it represents a breccia of small fragments of the rock recemented by the same hydromicacco-feldspathic material.

Past this large belt, red jasper-banded mixed ore appears in

a second belt much wider than the first. It exhibits the same corrugation of its layers, and on its line of contact with the hydromica-schists on the south side both kinds of rock are interlocked by long spurs and loops projecting from one belt far into the other, in proof of the high degree of plasticity of both of these very different rock masses at the time they became interlocked. On the north side of this jasper-banded mixed ore belt, we find the same kind of hydromicaceo-feldspathic schistose rock succeeding it, which joins its south side; also this belt has a much shattered brecciated structure and considerable width. Next in the succession, a wide belt of banded magnetic quartz-schists follows, the structure of which is very similar to the red jasper-banded rock belts before met with, but the quartzose seams of this rock are dark brown, also blackish colored, and the intermediate ore seams and oxide granules disseminated through the whole mass are not, as in the former rock belt, martite or sesqui-oxide, but consist of magnetite. The amount of magnetic ore contained in this belt is quite large, but not concentrated into seams large enough to be properly mined. Several abandoned shafts which I encountered witness a great amount of labor unsuccessfully bestowed on such localities. This region is at present overrun with exploring parties, most of which, relying on the dip needle as a guide in their explorations, principally stuck to one of these belts of magnetic schists and found themselves disappointed, instead of hunting for the large martite ore masses near by, which exert much less influence on the needle than the other, and have therefore to be traced by outcrops, and by learning their relative position with regard to the magnetic schists in a given locality.

Proceeding north across this wide magnetic schist belt, we come once more to a belt of schistose hydromicaceous beds interstratified with light colored quartzite belts, which series of rock beds continues down to the shore of Lake Vermillion, which is dotted with a great number of larger and smaller islands.

Standing at the shore near the quarter-post on the north line of Sec. 27, T. 62, R. 15, on outcrops of a white granular quartzite with an abundant sparry calcareous cement, we observe some distance farther north, on a projection of the land into the lake, a ridge about 50 feet high, trending parallel with the hills on our side, which is formed of another succession of magnetic

schists, the same in quality as the former belt, and on a large island farther to the north, the white cliffs bordering its shore are from the distance recognizable as a repeated outcrop of a belt of quartzite beds and hydromica-schists, which fact is ascertained to me by persons who have been on the island.

This cross-section from the mines to the shore of the lake and out into its islands, in all probability represents not one continuous succession of superimposed rock beds, but a repetition of beds by existing plications, which to demonstrate positively, a cursory examination like this was insufficient.

Southwest of the hill just described, on the north side of the village of Tower, this same rock series with interstratified belts of iron ore is displayed in another range parallel with the former. Farther south, about a mile from the mines, on the side of the railroad, I noticed large exposures of the light colored quartzites mingled with hydromicaceous schists, which beds, according to the descriptions of woodsmen familiar with this part of the country, form the surface rock over wide spaces. They seem to be the highest strata, through which deeper seated ferruginous strata came to protrude by means of great plications of the surface crust and subsequent erosion. Four miles south of the mine, near the engineer's camp, the railroad cuts through a large series of compact blue colored slate-rocks dipping north under high angle; between the fifth and ninth mile south of the mine, are other cuts through bluish colored quartz-schists, some of which beds are crowded with silvery shining mica scales; these beds have great resemblance to certain layers of the staurolitiferous mica-schist formation near Michigamme Lake. About twelve miles south of the mine we reach the base of Mesaba Heights, which consist of eruptive granite masses, well exposed naturally and in cross-cuts made by the railroad. After crossing the heights on their south side the entire group of beds, magnetic schists, hydromica-schists, hematitic ore belts, etc., occur again, succeeded further south by blue slate-rocks like those near the engineer's camp. These beds, flanking the south side of Mesaba Heights, are identical with those on its north side and on Vermillion Lake, but while the latter are found in nearly upright position and much distorted, these are gently dislocated and dip under comparatively low angles southeastward.

A few miles further south, about forty-six miles from Agate

Bay, the roadbed makes a cut through hillocks of coarsely crystalline olivine-bearing gabbros and for four or five miles, further on, these gabbros are again repeatedly intersected by the roadbed. This gabbro belt can be traced in continuous exposures southwestward to the city of Duluth, where in the south part large bluffs of it project and are quarried for building purposes, for which they are admirably adapted, as they are very durable and take a fine polish if used for ornamental masonry.

From this gabbro belt, which disappears under drift masses about forty miles off from Agate Bay, no more rock exposures can be observed aside of the railroad line, until about two miles this side of the harbor, where the diabases of the Copper-bearing rock group begin to show themselves at the surface and do so all the way down to the shore. The strike and dip of the entire rock series from Mesaba Heights to the shore of Lake Superior appears to be in perfect conformity.

The blue slate-rocks intermediate between the iron-bearing rock belt and the gabbro belt on the south side of Mesaba Heights and also found above the ore-bearing beds of Vermillion Lake, four miles south of the mines, are vastly denuded in the bed of St. Louis River, between Thompson and Fond du Lac.

Considering their position above the ore formation of Vermillion Lake, which in its entire complex has so much resemblance with the ore-bearing rock group of the Marquette district, that I identify them without hesitation, and comparing the slate formation with the equally large succession of slate-rock beds in the environs of L'Anse Bay and Huron Bay, which likewise occupy a horizon high up in the Huronian series, I find so complete a similarity between them, that their analogy is not to be doubted. Noteworthy is the frequent intersection of these slate-rocks by diabase dykes on St. Louis River and near L'Anse, and on the other hand the scarcity of such dykes in the lower beds of Vermillion Lake district, where none came under my observation during the short time I had for their examination. It was likewise unexpected to me to find in connection with the granites of Mesaba Heights, no diorite rock belts in the exposures on the railroad.

CHAPTER V.

ARENACEOUS SLATE GROUP.

The large succession of rock beds comprehended under this name in my preceding report, is represented as varying considerably in its lithological character in different localities of the small area of the Marquette region. Extending my observations over the western part of the Upper Peninsula, where corresponding beds are widely spread as surface rocks, I found them to differ greatly from those already described, still, considered in its totality, the group there is also mainly composed of arenaceous and slaty rock beds.

I could not avoid to enter several times into a description of rocks belonging to this horizon, in the previous chapter, as they occurred in close association of other older rocks, which separately to describe would have been inexpedient.

This group is of high economical interest, as it encloses immense stores of iron ore, which were partially known to the miners for a good while, but their relative position in the Huronian series has only recently become more clearly known.

During the past five or six years the attention of explorers for iron ore has directed itself earnestly to this geological horizon and within that short interval a great number of ore deposits of surprising magnitude have been discovered almost everywhere, as far as the formation extends. The principal masses of ore are found in a hydrated condition, but specular hematite and magnetic ores are not altogether excluded.

In a foot note of the previous report, on page 130, I mentioned as belonging to this group the ore deposits of the Taylor mine, in the vicinity of L'Anse, of the S. C. Smith mine, now called Cheshire mine, southeast of the Cascade mines, and of the Northampton and Dalliba mines, north of the Champion mine, to which at present a number of other localities could be added.

As I did not describe any of them, I let here follow a description of some of them.

The Taylor mine, one of the older mines worked in the district, but at present abandoned again, is located on the summit plateau of the granite stock intervening between Lake Michigamme and the Bay of L'Anse; the mining property being in the N. E. ¼ of the N. W. ¼, Sec. 9, T. 49, R. 33. Following a sidetrack from the Houghton & Ontonagon R. R. to the mine, we find the surface for almost the whole distance covered with drift deposits. The first rock exposures encountered are about 500 or 600 steps from the mine; they consist of graphitic slates, which dip under a high angle to the south; their visible thickness is about 200 feet. The outcrops are then interrupted by a swampy depression, on the other side of which succeed banded jaspery strata, composed of alternating narrow seams of whitish or brown colored flinty quartz and similar seams composed of compact dark brown limonitic ore, partly also of a mixture of limonitic with specular ore, which gives the seams a metallic lustre. Abundantly associated with these ore bands are also concretionary masses of pyrolusite in brightly shining radiated crystal clusters, by which fissures and druse cavities in the rock are sometimes totally replenished.

Having passed across about 250 feet of this belt, we see its ledges bent into an anticlinal arch, in which the anticlinal portions are pressed into parallelism with the former succession; the whole series of beds therefore dips south, the beds in the center of the arch being nearly vertical. Advancing farther on the road, which makes a deep cut into these beds, another similar fold occurs, then a diabase belt, sixty feet wide, diagonally intersecting the ledges, is met with. On the south side of the diabase belt graphitic schists are in contact with it, which dip south like the former series. The width of this belt is considerable. Past it succeed again the banded jaspery layers, in alternation with ore seams identical in appearance with those on the north side of the diabase belt. Next to them, southward, follow softer shaly or slaty argillites with from time to time interlaminated quartzite beds in a wide belt, which is more or less deeply red tinged by impregnation with hematite oxide. It encloses seams of a soft crumby iron ore of partly limonitic, partly hematitic condition, which seams locally widen into

pockets thirty feet in diameter, and much longer in the direction of the bedding. On the other side of the belt we meet again with the banded jaspery rocks and with graphite-schists on their south side. The so far described cross-section embraces the space from the north line of the section to its center.

Proceeding farther in this direction are seen repeated outcrops of graphitic schists, of heavy quartz layers of light color, intersected by fissure seams filled with limonitic ore, which widen sometimes into pockets; and again, of the ore-banded jaspery series with temporary interruption of the exposures by drift-covered spaces.

Approaching the south line of the section, a round ridge of diabase, trending from east to west, stretches across our way; it is a rock identical in appearance with the diabasic dyke rock above mentioned.

On the south line of the section, eighty rods west of the eastern section corner, graphite-schists, dipping under high angle south, are well exposed in test-pits. Other test-pits are 200 feet farther west, in which the ore-banded jaspery strata are exposed; near the quarter-post these jaspery layers are interstratified with intensely red colored, slaty argillites, which sometimes are replaced by deposits of soft hematite ore intermingled with limonite, widening into pockets. The explorations at the time had not far enough advanced to ascertain the extent and value of these deposits. The strata repose in steep inclination on the south slope of the hills, directly underlain by the before mentioned diabase belt and overlain by compact, but well laminated hydromica-schists consisting of a mixture of coarse opalescent quartz grains and fragments of red feldspar crystals, embedded within a groundmass of silky shining hydromica with chlorite. These beds, forming the surface of the slope of the hill down to the bed of Plumbago Creek, are succeeded on the other side of the stream by similar schistose beds much richer in red feldspar and containing only little quartz, which could be, on superficial examination, mistaken for granite, but are evidently a fragmental rock, formed of the detritus of the granite, which, near by, forms large mountain masses. The granite of these mountains is very rich in red feldspar and contains, comparatively, not much quartz; it also has a more or less distinct, seamy, laminated structure, and being in close contact with these schists, it requires great

care to make proper distinction between the two, in origin, widely different rocks.

A half mile south, in the center of Sec. 16, after having crossed a granite hill, we find on the south side of another creek, tributary to Sturgeon River, a number of old exploring pits for iron ore. The summit part of this hillside is formed of similar quartz-bearing hydromica-schists as those near Plumbago Creek; some of the layers are much finer-grained, with no quartz grains in them. Beneath them follows conformably a large series of banded ferruginous quartzite layers, inclosing irregular seams and pockets of limonitic iron ore, but an exploring tunnel driven into these beds for quite a distance, does not show the intersection of any such ore seams which would be worth mining.

The base of this hillslope is formed of granite, but the talus, surrounding the projecting rock walls of the iron-bearing strata, covers up their contact line with the granite. On returning from here, I came to Plumbago Creek, a half mile below my first crossing place. Ascending the slope on its north side, I could observe, some distance above the sole of the valley, graphitic slates and associated banded ferruginous jasper strata, reposing discordantly on the granite, with steep inclination to the south. Higher up the slope the same beds are in discordant contact with the prolongation of the mentioned diabase belt, running along with the south line of Sec. 9, and forming vertical cliffs at the edge of the summit of the hill. Following from here the west line of Sec. 9 northward, I found, near the quarter-post, extensive exposures of hydromicaceous quartz-schists of silvery lustre. Beneath them, conformably dipping to the south, follows a large belt of banded ore-bearing quartzites, then comes a belt of graphitic slates, then again a wide belt of the banded ferruginous quartzite beds, the latter well exposed in the bed of a creek, which passes the mining camp one-quarter mile further north, and is not far off from the north line of the section. This quartzrock series is full of seams of limonitic ore, but none of them are large enough to begin mining operations.

I observed a similar succession of rock beds in various other localities in this vicinity, particularly in the south half of Sec. 4.

The slate rocks of L'Anse which are outcropping in many places along the Houghton & Ontonagon R. R., and evidently

compose a portion of the mountains on which the Taylor mine is situated, I could never see coming in contact with these ore-bearing beds. Taking in consideration the topographical distribution of these rocks, it appears to me probable, that the slate formation succeeded immediately beneath the Taylor mine group, as it is north of the Taylor mine, and dips south under its layers. Small deposits of hematitic iron ore and siderite occur within the roofing-slates, near the slate quarries of Huron Bay, about a half mile lower down the creek bed. The belt is about thirty or forty feet wide and the ore is mingled with decomposing cherty limestone layers, probably resulting from the decomposition of sparry carbonate of iron, as some of the hematite is found in the form of spar crystals. Practically these ore deposits have no value. Brittle, dark brown, flinty layers are found intermingled with the slate-rocks adjoining this belt on the south side; on the north side of it are bluish-gray arenaceous argillites, interlaminated with similarly dark colored granular quartzite ledges. North of these, a belt of white granular quartzite, 400 feet wide, follows; farther north gray, drab, reddish or yellowish colored slate-rocks, much softer than the roofing-slates, follow each other all the way down to the shore of the bay, in a belt not far from a mile in width, of which a description is given in the previous report. Numerous dykes intersect the slate-rock series; some, particularly the narrower ones, often not over a few inches wide, consist of a fine-grained, almost aphanitic compact mass of greenish-gray color, which under the microscope appears as a turbid, little transparent, granular mass, in which clear prisms of very minute size are disorderly scattered in great quantity. Larger dykes of coarser crystalline structure exhibit under the microscope the composition of the ordinary diabasic dyke masses, met with in all horizons of the Huronian group. Clear prismatic plagioclase crystals, in intermixture with augite, transparent with brownish color, and some granules of titan-iron or of magnetite, are the constituents. Part of the augite is externally changed into viridite.

A coarsely crystalline diabase dyke, thirty feet wide, forms a conspicuous hillock on the north side of the Houghton & Ontonagon R. R., 200 steps off from the road, and about midway between the fifty-eighth and fifty-ninth mile post; the strike of the belt is east and west; it intersects a coarse breccia of white quartz

fragments and some granite fragments, cemented by a dark, greenish gray colored silico-feldspathic mass; above the breccia belt, succeeds a compact, fine-grained rock belt of delicately laminated structure, which lamination becomes very obvious on weathered surfaces. It consists of the same dark greenish colored silico-feldspathic material as the cement of the breccia belt; weathered surfaces lose their color or become white. In its course the dyke comes in immediate contact with this upper belt and seems to have had the effect of making it much more compact and hard on the contact line; the higher layers of this belt gradually change from the compact into a fissile slaty form, and next succeeding to these are genuine roofing-slates. The dip of all this conformable succession of sedimentary layers is southward. A good quality of roofing-slate is also uncovered in trenches made next to the railroad, near the sixty-first mile post, counting the distance from Marquette.

Rocks analogous with those at the Taylor mine extend on the south side of the Houghton & Ontonagon R. R. in a broad belt westward from Lake Michigamme. Thick drift deposits cover the surface in that part of the country; rarely the underlying beds are naturally exposed, but numerous exploring pits, dug within the past five or six years all over this tract of land, give ample occasion to observe the succession of beds.

The strata dip south under a high angle. Graphitic slates are the lowest ones denuded; they amount to considerable thickness. Above them follows a large series of thinly laminated, flinty or granular quartzite strata in regular banded alternation with similarly thin seams of limonitic iron ore more or less contaminated with siliceous matter. Within this series locally occur larger seams widening into pockets from twenty-five to fifty feet in width, and traceable for several hundred feet lengthwise, which consist of soft, crumby, limonitic ore, almost free of intermingled quartz seams. They average in the furnace from fifty to fifty-five per cent in metallic iron; but like in all ores taken from this horizon, the amount of phosphorus is larger than admissible for the use of this iron in the steel manufacturing processes. South of the ore-bearing layers, banded, ferruginous quartzite strata extend for some distance, interstratified from time to time with dark, pyritous, slaty layers. South of them again graphitic schists occur, but I did not ascertain whether

such repetition of the strata is caused by their plication or by an actual repeated succession of similar beds.

This same complex of rock beds is seen continued on the east side of Michigamme village, and is in direct connection with the large display of the same formation on the hills north of the Champion mine, in which places the Northampton, Dalliba, and a great many other mines have been opened recently and produced a large amount of ore for the market, but at present the depression in the value of iron necessitated the suspension of work in most of them.

On the east side of Michigamme, these strata are much more impregnated with actinolite than on the western continuation of this belt. On the landspur projecting into the lake, across the north part of Sec. 28 and the north half of Secs. 27, 26 and 25 of T. 48, R. 30, a large belt of actinolite-schists, richly impregnated with magnetic granules and banded by solid seams of magnetic ore, which belt most likely corresponds with the actinolite-schists directly overlying the ore-bearing strata of the Michigamme mine, forms the lowest layers exposed; their dip is northward. Above them succeeds conformably a large series of graphite-schists, which farther north disappear in the bottom of a swamp, north of which granite and diorite bluffs briskly ascend, or in some places before we come to the granite bluffs, strata of the red jasper-banded rocks, alternating with bands of siliceous specular ore, are found to lean on these with southern dip.

Towards the east end of Michigamme Lake, the before mentioned belt of graphite-schists is found to be overlain by the limonite-bearing, banded quartzrock layers laid open in the mining pits west of Michigamme and south of the railroad, in which, a short distance east of the lake, miners have done a great amount of work. The oldest and most important mining pits in this eastern part of the ore-bearing series are the Northampton and Dalliba mines, the first situated in the S. E. ¼ of Sec. 30, T. 48, R. 29; the latter in the S. W. ¼ of Sec. 29.

The succession of beds is favorably exposed on the sidetrack of the railroad leading to the mines. At the base of the south slope of the hillside, gray-colored, compact quartzite beds, or in place of them a coarse breccia of quartzite fragments of various color, firmly cemented by a dark colored, schistose, interstitial

mass, are seen as the lowest; they are in an almost upright position and dip north. Next above conformably succeeds a belt of well laminated, banded, quartzose, actinolite-schists, richly impregnated with magnetite granules; the width of this belt is about 100 feet. North of the actinolite-schists a space of about 200 feet is covered; on the springy surface a sheet of bog iron has formed.

Ascending further, we come to a belt of almost vertical layers of graphite-schists, about 100 feet wide; their dip is south. In conformable succession, underlying them, follows a belt not less than 200 feet in width, of heavy, gray colored, quartzite beds interlaminated, from time to time, with seams of graphite-schists. Then again, a drift-covered space intervenes near the brow of the hilltop; farther back on the plateau crops out again a large body of steeply erected graphite-schists, dipping northward. They form the foot-wall of a still larger series of the banded, jaspery quartzrock, in alternation with similarly narrow bands of limonitic ore and interstratified with schistose argillitic beds more or less intensely impregnated with hydrated oxide, besides seams of pure limonitic ore, which widen locally into large pockets. This ore is partly soft, crumby, ochreous, partly forms compact, aphanitic masses with smooth, conchoidal fracture; much of the ore occurs also in the radiated crystalline form of grape ore, composing stalactites of great beauty, which are, on the surface, heiter covered with a smooth, brightly shining, black, varnish-like cuticle, or this cuticle has a brilliant velvety lustre, or else larger scaly and needle-shaped crystals of goethite cover their surface. Druse cavities are sometimes lined with radiated clusters of quite large crystals of goethite and with colorless quartz dihexahedrons. Proceeding from the Northampton pits northward across the strike of the formation, we observe that the strata have suffered repeated plications into synclinal and anticlinal folds, as we find next north of the mine repetitions of the same beds in an inverted order and dipping southward, and then again the same series dipping northward for a second time. North of these folds, in which ore beds are disclosed, another anticlinal arch is formed by graphite-schists and by underlying, compact, gray colored, heavy quartzite ledges, identical with the beds exposed south of the Northampton pits. The northward-dipping part of this anticlinal fold forms the northern slope of the hill range, but towards

the base of the hills the strata disappear beneath drift deposits. A head branch of the Escanaba River washes the foot of the hills, and on the other side of the channel, within short distance, a granite range faces the river with vertical cliffs. The same succession of beds, bent into repeated folds, is observable by starting from the old Champion furnace, across the hill range to the location of the Dalliba mine.

The bluffs at the furnace are composed of dark actinolite-schists; overlying them are graphite-schists, interlaminated with compact quartzite beds, which strata cover a wide belt, but toward the top of the hill-plateau drift deposits hide the rock ledges, until after a while another undulation of the surface caused the denudation of actinolite-schist, graphite-slates, quartz beds, etc., and so on to the mine, which is opened in the continuation of the Northampton belt, and needs therefore no special mention.

East of the Champion furnace the lithological character of the geological horizon soon changes. Actinolite ceases to be an important constituent of the lower beds, the graphite slate-rock series continues to be well developed for a number of miles further east, but of limonitic ore deposits in that horizon, nothing more is observable in that direction. The strata subjacent to the graphitic schists, and above the iron-bearing rock series of the Champion and other equivalent mines, amounts to a very great thickness. These beds are all well laminated, of sedimentary origin; by recrystallization of the material the rocks have become very compact, like eruptive rock masses, particularly in the lower horizons; the higher beds have generally a slaty structure. High bluffs of these rocks are exposed in the hillsides on both sides of the railroad between the Champion mine and the Washington mine, and onward to Clarksburg. The compact, crystalline rock beds of this group consist of a granular, siliceous and feldspathic groundmass, almost invariably intermingled with a large proportion of carbonate of lime, or also dolomite or siderite, and besides, the mass is always plentifully interspersed with chlorite and mica scales; often also an abundance of green hornblende prisms is unequally scattered, or more concentrated within certain seams of the laminated rocks which exhibit often serpentine corrugations throughout their mass. Very generally a part of the ledges in the succession has the structure of a breccia composed of small fragments, but occasionally enclosing larger segments of a banded

succession of several superimposed layers of rock; the cemented rock fragments appear sometimes corroded on the periphery and merge with the cement mass without a sharp line of demarcation. The great amount of lime in the composition, which readily dissolves on exposure of the rock, causes it to weather with a very rough, cavernous surface, and in cases where siderite is substituted for carbonate of lime these cavities and cells of the weathered rock are found replenished with ochre of yellow or brownish red color.

On the north side of Clarksburg larger lenticular seams of a whitish colored compact dolomitic lime-rock are found, interstratified with the just described rock masses, which project there in a long row of vertical bluffs divided into several terrace-like offsets. In the same locality also a branching dyke of a fine-grained diabase is seen to intersect the strata. As before stated, the higher beds incumbent on this series are all slatelike, consisting of a fine-grained feldspathic and siliceous groundmass, crowded with minute mica scales or else chloritic scales. The mica and chlorite scales impart to many of the layers a satin lustre on the slaty cleavage planes usually intersecting the sedimentary lamination under an angle, which latter is often indicated by stripes of different color. In this upper slaty series, for the lower 300 or 400 feet, the dark green color of the rock belt below is not often seen; lighter gray tints, shading into bluish, brownish, reddish or a banded alternation of such colors, are most common, but the color of the highest beds in the succession is black, from carbon or graphite combined with the rock material.

The uniformity of this slate-rock series is interrupted from time to time by interstratified quartzrock belts, light colored or dark brown, by ferruginous matter, but actual deposits of iron ore, which farther west occurred in association with these graphite-slate layers are, as I had previously remarked, no more encountered east of the township, R. 29, on north side of the Houghton & Ontonagon R. R. South of that road, along the course of the Escanaba River, where analogous slate-rock and quartzite strata are found in isolated outliers, spread over an area generally composed of granite rocks, rich limonitic and partly hematitic ore deposits are found in association with them.

The Cheshire mine, formerly known by the name of the S.

C. Smith mine, from its discoverer, is working such a strip of slaty and quartzose rock beds, known to extend along the valley of Escanaba River for a distance of nine miles, from the N. W. corner of Sec. 19, T. 46, R. 26, to the center of T. 45, R. 26. Farther south similar iron-bearing rock beds occur in the vicinity of Little Lake. The old pits of the Cheshire mine were opened in the N. W. ¼ of the N. W. ¼ of Sec. 20, T. 45, R. 25; the presently worked pits are in the S. E. ¼ of the S. E. ¼ of Sec. 18 and in the S. E. ¼ of the N. W. ¼ of the same section. The surface in these localities is generally covered with drift; natural outcrops are very limited.

The following succession of beds is observable in the mining pits: Trending to the northwest and dipping northeast are lowest, black graphitic slate-rocks, some very fine-grained, homogeneous, other seams arenaceous, by copiously intermingled quartz grains. At intervals compact, dark colored granular quartzite ledges are interlaminated. This series reposes on a dioritic rock belt. Next above the graphitic slate belt follows a series of light colored quartz ledges and of banded jaspery layers, with alternating lighter and darker brownish colored seams. The greater portion of these quartzrocks is shattered into small fragments and firmly recemented into a breccia. Incumbent are rough cellulose cherty quartz beds, the cell spaces filled with yellow ochreous matter, above which a broad belt, irregularly widening and contracting, is formed by a crumby, not distinctly stratified accumulation of brown limonitic iron ore of dull earthy appearance, with interspersed harder concretionary masses of open cellulose structure, consisting of martitic ore granules of metallic steel-gray color, the cell cavities of which are often lined with a velvety coating of goethite, or totally replenished with radiated-fibrous clusters of this mineral. In some portions of this ore belt occur also lenticular accumulations of impalpably fine scaly hematite ore of bright, purple colored satin lustre, which, without any further preparation would answer for paint of the bronze type. The hanging of the productive ore seam is made up of a large, very much distorted and corrugated or broken up and faulted succession of ferruginous chert beds, partly in thin, flaggy layers, partly thick-bedded and cellulose, which group of siliceous rocks encloses many irregular lenticular seams of ochreous limonite, of the granular metallic

shining martite, in soft friable masses, like the blue ore of the Menominee region, and of red hematite ore, soft, or in compact masses.

The larger seams of ore in this upper series of beds are mined out and furnish, taken together, nearly as much ore as the underlying belt. In the lower part of the hillslope, after short interruption of the exposures, graphite-schists are naturally exposed, in a conformable superincumbent position with regard to the described series of the pits. A mining tunnel opened on the northwest quarter of Sec. 18 gives another opportunity to observe a cross-section through the group of beds. The entrance is at the base of the hillslope, only a few steps from the bed of Escanaba River. In descending order it intersects, first a belt of graphite-schist, forty feet wide, in steeply erected position; next below, a much larger belt of gray and red colored micaceo-argillitic schists follows, then comes a belt of quartzrocks, near 200 feet wide, some ledges of which are thick, heavy, but the majority consists of a banded, thinly laminated series of alternately lighter and darker colored jaspery seams, and the greater part of this rock belt is shattered into fragments with more or less faulted dislocation of the corresponding broken ends of the layers, but without causing a chaotical disorder and dissolution of the beds, which are solidly recemented by infiltration of iron ore into the small fissures and larger crevices between the fragments. These reticulated seams of ore are partly an aphanitic compact brown colored limonite, mingled with radiated grape ore concretions, partly the cementing ore masses are purplish gray with metallic lustre and consist to great extent of hematitic oxide and of goethite, which mineral occurs in solid radiated crystal bunches or as velvety incrustation of the grape ore concretions. The larger seams of ore in this shattered rock belt are mined to advantage, but the greater portion of this excellent ore in the network of smaller seams is unavailable, as there is no way of separating it from the quartzrock. Underlying this brecciated ore-bearing quartzite belt, are the graphite-schists interlaminated with arenaceous seams and black colored compact quartzite beds, which were described as being the lowest in the cross-section of the other mining pits, in contiguity with a diorite belt and close to granite outcrops.

In Sec. 19, T. 46, R. 26, where Mr. Lonsdorf made explorations

for iron in the same group of deposits, as the lowest beds reposing on granite, again graphite-schists occur, which are interlaminated with quartzite layers and enclose also irregular lenticular seams of limonitic iron ore; much of this belt is broken up into fragments, which became recemented again by infiltration of limonitic iron oxide.

Above these layers a belt of micaceous-schistose quartzites follows, brown colored by impregnation with hydrated oxide of iron, and the uppermost rock ledges observable in the locality are thick compact beds of a reddish colored granular quartzite. The general surface rock of the surrounding country is granite, associated with diorite belts intersecting it. The granite masses underlying the sedimentary beds in this locality are usually in progress of decomposition, whereby the feldspar has changed into a soft kaolinitic substance. The ore deposits found there were not sufficiently large to promise to be of much value for the miner and the work had been abandoned at the time of my visit to the place.

Reviewing the southwest part of the Michigan territory in Lake Superior region, where, as stated in my previous report, areas, many hundred square miles in extent, are covered with the upper series of the Huronian sedimentary layers, in which immense deposits of limonitic iron ore were discovered, I find during the past few years the number of such discoveries vastly augmented by the unremitting zeal of explorers, although their disappointments much outnumber their successes in their hard and expensive work. This younger group of sediments, enclosing limonitic ore deposits, shows by its topographical distribution an independence from the preceding lower strata, which proves considerable changes in the ocean level during the time intervening between the deposition of the first and the latter.

In the Quinnesec mining district no interruption in the progress of formation of sedimentary layers is indicated, as we find on the north side of the Quinnesec iron range its latest strata, the great belt of compact siliceous limestones, conformably succeeded by this very large group of sericitic argillite-schists, graphitic slate-rock layers, chert and quartzite belts, with interposed accumulations of limonitic iron ore, but further northwest, partly on Wisconsin territory, the most common case is to find this upper series of rock resting on dioritic and granitic masses, and

none of the lower strata developed. Among the recently discovered productive fields for iron mining, the vicinity of Crystal Falls has become famous for its wealth in ore. The formation enclosing the ore deposits, has there a great thickness, but its determination by actual measurement is impossible on account of the much folded condition of the strata, and for want of connected exposures transverse to the stratification. Estimating its thickness to several thousand feet is surely not far beyond the truth. This folded condition of the strata is in many instances an obstacle in the decision, whether in a given locality we have under observation a descending or an ascending succession of beds.

If we follow the railroad from Crystal Falls village upward along the bed of Paint River, we find, in the first cut the road makes into rock beds, a series of hard, black slates, transversely intersected in almost vertical position, and according to their cleavage planes, dipping in southwest direction. This cross-cut is 210 steps long; thence, for the distance of 100 steps, no rock ledges are touched by the roadbed, but on the left side of the road similar slate-rocks are denuded, which apparently represent a continuation of the former succession. From here for eighty steps a cut is made through similar slate-rocks, but interlaminated with numerous quartzite seams; further on, the intersection of slates in alternation with quartz seams continues for quite a while, but these slate-rocks are more graphitic than the former and readily disintegrate, on exposure, into splintery fragments, as they contain a large proportion of iron pyrites and rusty ferruginous seams causing the decay. By this time we have reached close to the river below its falls, and find, laid open in its embankments formed by the bluffs thirty feet high, a further conformable series of graphite-schists, 300 feet wide. Beneath the graphite-schists, close to the water level at the foot of the falls, succeeds an ore belt, six feet wide at the surface, but widening to fifteen feet, followed into the hillside. This ore seam is quite heterogeneous in its composition; the bulk of it is an earthy ochreous mass, enclosing harder concretionary masses of compact limonite, with conchoidal smooth fracture, besides others formed of crystalline nodular or stalactitic grape ore agglomerations.

Another portion of the ore is found in the non-hydrated condition, either as soft earthy hematite or in compact concretions

with smooth conchoidal fracture of dark purplish color. Quite frequently such harder hematite concretions were intersected by a network of seams, consisting of fine-grained specular ore with bright metallic lustre, and cavities in these concretions were lined with lentil-shaped, purplish black brilliant crystals of oxide in association with prismatic crystals of goethite. For a short time this ore belt had been mined, but the work is now abandoned, as the close proximity of the openings to the water level of Paint River was an inconvenience, and the ore belt itself, by being followed, instead of widening, as it first did, contracted again.

Below the ore belt follows an immensely large succession of thinly laminated banded ferruginous quartz-schists of dark, rusty color, which beds, in steeply erected position crossing the river-bed diagonally, give a cause to falls eight or ten feet in height. The exposed succession of beds amounts at the falls to a thickness of over 800 feet. Intermixture of pyritous shaly seams with the quartzite beds, induces their rapid disintegration on exposure, into shelly fragments covered with an iridescent varnish-like coating of oxide-hydrate. These beds are, in the embankments on the opposite river-side, remarkably corrugated, describing in their flections perfect coils.

This is approximately the horizon in which the principal ore deposits occur in this vicinity. Not far off from the river extensive ore deposits have been laid open by the miners in the S. E. ¼ of Sec. 20, and in the S. W. ¼ of Sec. 21, T. 43, R. 32. Still more promising are the explorations of the Briar Hill Iron Company, in the S. W. ¼ of Sec. 20, and S. E. ¼ of Sec. 19, on which locations a belt of marketable ore 100 feet wide is claimed to be found. At the time of my visit, the trenches were not fairly opened, but it was plainly visible the deposits were very large and of good quality, principally limonite, but partially hematite, which is usually the case in all the ore belts of this formation.

A great many other explorations in the wider circumference of Crystal Falls could be enumerated, which met with more or less success, but to describe all these places would involve a useless repetition of the same structural features delineated previously.

Another mining center working the ore beds of this formation is near Chicagon Lake and on Iron River, which regions have, to some extent, been considered in my previous report; but since

the time of my first visit to these places a vast amount of exploring work has been done there, by which the value of the already known ore deposits was more positively tested and a great many other new discoveries were made.

An uninterrupted continuity of the rock formations connects this region with the Crystal Falls region, and west of Iron River the same complex of strata spreads yet over wide areas. These parts of one and the same basin exhibit therefore, excepting unimportant local differences, a harmony in their structure, which, after one part has been examined and described, leaves little new to be reported about the other part; I can therefore be short in my further remarks concerning this region. A few new localities examined by explorers and the progress since made in the exploration of the previously described places on Iron River may be here the objects selected for illustration of the structure of the entire district.

Interesting are the explorations made under the supervision of Mr. Bordman, in the N. E. ¼ of Sec. 26, T. 43, R. 34.

The surface in this locality is covered with drift deposits; my observations had to depend therefore on the inspection of the test-pits, systematically located so as to intersect the formation transversely.

The general trend of the strata is northwest, their dip northeast, very rarely vertical; but the beds are subject to frequent plications, and often abrupt ruptures of the belts, with more or less considerable faulted location of the broken ends, are observed, which circumstances are very annoying for the miner, and an impediment for the geologist in his efforts to find out the true order in the succession of beds, which as far as I could learn is as follows: Farthest south, and consequently lowest, a broad belt of graphite-schists occurs, succeeded by a large series of banded, siliceous beds, consisting of alternating, narrow seams of flinty quartz, in different shades of brown, yellowish or reddish colors, with interposed seams of compact limonite. These beds are much corrugated and fractured with dislocation of the seams, but recemented again by infiltration of limonitic ore, of which larger pockets, locally expanding to the width of forty and fifty feet, are met with in this series.

This ore is dark, blackish brown, very compact, with aphanitic, smooth, flinty fracture; its powder is yellowish brown; it often

encloses numerous angular fragments of the quartzrocks surrounding the pockets, in proof of its secondary infiltration into crevices of the quartzose rock belt.

North of this series, a wide belt of silico-argillitic, slaty rock beds and flagstones follows, varying in different colors from light gray to dark red. Within this group of beds deposits of soft, blood-red hematite are found irregularly wedged in, some of which ore seams are large enough to be mined.

Farther north the mining pits were not extended. A chemical analysis of the compact, limonitic ore of this locality gave, in 100 parts of the ore, 88 parts of iron oxide, 10 parts of water, and not quite 1 per cent of insoluble, siliceous matter; but the proportion of phosphoric acid was unusually large, amounting to 1.7 per cent of the ore.

The explorations in the localities on Iron River which were mentioned in the previous report, have since that time been vigorously continued with great success. In the N. W. ¼ of the N. W. ¼ of Sec. 36, T. 43, R. 35, a limonitic ore belt, from 80 to 100 feet in width has been discovered, and its extension lengthwise is traced for 900 feet. A similar belt of good limonitic ore, 32 feet wide, has been laid open in the southwest quarter of the same section.

Equally rich ore deposits were found on Mr. McKennan's property, in Sec. 26 of the same town, and other explorations in progress in the same neighborhood promise similar favorable results. The nature of these ores is in all the localities pretty much alike. Soft and compact limonite, mingled with crystalline grape ore concretions, forms the great bulk of the deposits, but in nearly every one of these localities, also red hematite ore masses occur in association with the limonite.

CHAPTER VI.

MICA-SCHIST FORMATION.

Regarding the age of this group, which I had but little examined at the time I published my previous report, I had to change essentially the opinion I then held, which changes of my views I have already expressed on several occasions, in the previous pages.

Seeing, for the first time, this large series of beds which borders the south shore of Lake Michigamme, opposite the village, dipping south in conformity with the strata of the Michigamme mine, and observing in the intermediate space a wide belt composed of graphite-schists and banded, ferruginous chert beds, inclosing seams of limonitic iron ore, dipping in conformity with the rock series north and south of it, I unhesitatingly accepted the theory of Major T. B. Brooks, who represented the mica-schist as the youngest sedimentary deposits of the Huronian group, thinking the just mentioned succession of beds to be an uninterrupted series of layers, of which the most southern were the highest. This same locality, previously under consideration while I gave a description of the Magnetic mine and tried to determine the relative stratigraphical position of this ore-bearing belt of rocks, as I stated then, on more careful examination furnished satisfactory evidence, that the mica-schists in this cross-section are the inferior strata on which the limonitic and graphitic group of beds conformably rest.

This evidence consists in the clear recognition of typical garnet and staurolite-bearing mica-schists, on the north side, and conformably underlying the graphitic and limonitic group of rock beds, which northern belt of schists lithologically is identical with the mica-schists on the south side of the belt of graphitic and ferruginous rocks. This seeming repetition is accounted for

by a folding of the layers by which the incumbent youngest strata became wedged into a synclinal depression of the older.

The mica-schists of Michigamme Lake, according to this exposition, have their place in the middle horizon of the arenaceous slate group, and their consideration as a separate group of beds, younger than the others, should have been entirely discarded, but as the clear conception of the true position of these beds is a recently made progress which I made after this whole report was nearly completely written out, I retained the adopted method of communicating the recent results of the work of the Survey under the form of supplementary notes to the preceding volume, making in each place the necessary rectifications instead of undergoing the labor of a radical change in the arrangement.

After these explanatory remarks, the further information I have to give about the mica-schist group, in this and other regions, might as well be here expounded separately, as to be patched into the former chapter, comprising the arenaceous slate group, where it actually would belong.

A very good exposure of a descending section from the typical staurolite-bearing mica-schists down to the dark green colored garnetiferous biotitic and actinolitic schists analogous to those superincumbent on the ore-bearing belt of the Magnetic mine and likewise to those found largely displayed on the north side of the Keystone mine, of which a description is given in the previous report, occurs in T. 47, R. 30, Sec. 4. On an island in the south part of Lake Michigamme, the mica-schists of gray color, with silvery lustre, full of staurolite crystals, are largely exposed, dipping under a high angle to the west. A short distance east of this island is another smaller one, perfectly denuded of soil, formed of dark green colored biotite-schists, full of reddish colored garnets from the size of a pin's head to that of a hazel nut. They dip westward in conformity with the beds of the first island. Not over 200 feet east of this island is the main shore, on which a conformable series of dark gray colored compact quartzose mica-schists continues for the distance of about 200 steps transversely to them. The lower part of this series is a breccia, consisting of a granular micaceo-actinolitic dark colored groundmass, in which numerous angular fragments of well laminated, banded, lighter colored, siliceous rock are imbedded. Beneath the breccia follow dark blackish green coarsely scaly

biotite schists, very much twisted and corrugated; they are locally crowded with reddish garnets; other times a large proportion of dark green hornblende prisms helps to compose them. Interlaminated between these biotite schists are bands of well laminated, fine-grained siliceous substance. Portions of this rock belt consist of a crystalline hornblende rock of massive appearance, but it is merely a more compact modification of the other sedimentary beds. A belt of this hornblende rock projecting in cliffs on the shore line, is in the manner of an amygdaloidal rock, permeated with concretions of calcspar, which on the exposed surfaces has been washed out and leaves them perforated with cavities anastomosing as the holes in the coarser kind of sponge.

In the described locality a wide dyke of diabase is seen to intersect the strata transversely. The exposures do not continue further east into lower beds. A striking similarity exists between the lower portion of the described rock series and the rocks overlying the ore-bearing strata of the Magnetic mine; and not less perfect is their resemblance to the rock complex composing the hillslope on the north side of the Keystone mine. I consider them therefore as the representatives of the same geological horizon.

On Devil's Island, in the S. W. ¼ of Sec. 27, T. 48, R. 30, not far off from the north shore of the lake, the mica-schists, which there have a northern dip, are intersected by a large dyke of coarsely crystalline diabase, which holds a considerable proportion of olivine grains in its composition.

The strata exposed north of the island, on the main shore, are graphite-schists and actinolite-schists, impregnated with a good proportion of magnetite. These beds likewise dip north and represent the lower portion of rock complex, which higher up in the series incloses the limonitic ore deposits; it corresponds with the strata exposed at the Champion furnace. At the extreme east end of Michigamme Lake almost vertically erected, very much corrugated, well laminated rock ledges crop out, dipping to the north, which, in their lithological character, correspond with the mica-schists. The strata on the north side of the railroad track at this place, belong to the lower series of the Northampton mine rock-complex. The mica-schists in all probability continue eastward past the Champion mine, occupying the bottom of the valley, but are not exposed; the underlying series

of the rock beds of which above a description is given, is traceable on the southern row of hills, all along unto the Keystone mine, where the group of beds is extensively exposed. The large rock bluffs in Sec. 4, T. 47, R. 29, on the south side of the railroad, which I have previously described as well laminated compact gritty rocks, consisting of a micaceous quartzose and feldspathic groundmass, which generally contains also a good proportion of carbonate of lime and in certain seams is crowded with green hornblende crystals, in many respects resembles certain belts of the mica-schists exposed on the islands in Michigamme Lake; their stratigraphical position corresponds with that of the mica-schists. Tracing these rock belts farther east, their lithological character changes more and more, and the horizon of the mica-schists is no more recognizable.

If I am correct in placing the slate-rock formation of Huron Bay and near L'Anse as the strata next succeeding below the ore-bearing rock series of the Taylor mine, their position would correspond with the relative position of the mica-schists; the difference in the material of the two groups, one consisting prevailingly of gritty arenaceous material, the other more of impalpably fine mud sediments, is not of so great importance as to preclude their contemporaneous deposition under different local circumstances. The mica-schists seem to continue southward along the course of the Michigamme River, as we find in its lower course, five or six miles north from its entrance into the Brule River, and from there down to the mouth, mica-schist to be the prevailing surface rock. Along the lower course of the adjoining Paint River the mica-schists likewise are the only rocks seen in the exposures, and from the Michigamme downwards, almost to Badwater village, these same rocks are, except some eruptive diorite masses, the exclusive surface rock splendidly exposed in the river bed and in the hillsides bordering the river.

A good many miles northwest from the indicated localities, in the vicinity of Crystal Falls, this same rock must be somewhere at the surface, as I found at Crystal Falls in the drift a number of large angular blocks of the mica-schists full of staurolite crystals.

A description of the rock outcrops, from Badwater village up to the mouth of Michigamme River, I have given in the previous report, on pages 204 to 207, likewise of the outcrops for about a mile above in the Brule River.

At present I will describe the continuation of the cross-section the river makes through this formation, beginning at the mouth of Paint River and following the Brule River downward to the place which formed the end point of the previously described part of the valley.

At the mouth of the Paint River, the valley is a narrow gorge; the southern hills are eruptive diorite masses, against which the strata of the mica-schist formation abut unconformably with southern dip. Proceeding from here down stream, we ascend into higher beds of the series, which amount to much over one thousand feet of strata, until lower down the river a broad eruptive diorite belt diagonally crosses it. On the other side of this diorite belt, we have reached the above mentioned end point of former examinations.

The lowest beds seen at the mouth of Paint River, are an alternation of silvery shining minutely scaly mica-schists, partly in smooth fissile beds, partly corrugated into small wrinkles and also into larger plications with more compact gritty rock ledges, composed of a fine-grained mixture of quartz granules with grains of feldspar and with small brownish biotite scales. Most of these beds are gray colored, but also red seams occur, in which the feldspar grains (red orthoclase) prevail over the quartz grains.

This lower group of beds has a great thickness, as can be observed by following the Paint River from its mouth upward, where many hundred feet of strata are intersected by it, without an essential difference in the character of the ledges in any position, from one end of the exposures to the other.

The higher series exposed on the Brule River, below its union with Paint River, consists of comparatively softer schistose layers than the former; their composition is like that of the former rock, a mixture of quartz and feldspar granules with biotite scales in different proportions; if the mica prevails, they have a satin lustre; by prevalence of the quartz and feldspar sand, they are dull gritty. The color of the first 300 or 400 feet of beds is light grey, shading into greenish or reddish; in most of them the feldspathic component is more or less completely changed into kaolinite, and on exposure these beds soon disintegrate into a shaly heap of rubbish.

Higher up in the series, the schists have a dark greenish steel-

color, with considerable lustre; their color is due to the green color of the biotite scales in the rock substance.

Here and there, at this horizon, layers of quartzite are found interstratified.

The succession of the dark, greenish colored beds is very large. Some are cleaving like roofing slates, shining; others are dull, earthy in appearance, olive-colored. With these are interlaminated intensely red colored schists, by impregnation with hematite, some of them impalpably fine and homogeneous in their mass, others composed of coarse mica scales and kaolinized feldspar grains of white color, mingled with the hematitic and argillitic fine-grained or gritty quartzose groundmass.

Farther down stream, greenish colored, less schistose, bulkier rock beds, formed of a fine-grained mixture of feldspathic quartzose and micaceous composition follow in the succession, and soon after, this sedimentary series comes in contact with the before mentioned dioritic rock belt crossing the river. These last sedimentary beds seem to be formed of the detrital material of the diorite which, on its surface, is much decomposed, and friable by the pressure of the hand into crumbs.

The schists, richly impregnated with hematite, have here attracted the attention of explorers and on both sides of the river their abandoned pits are seen. The explorations on the Wisconsin side are known by the name of Ellwood mine, those on the Michigan side were undertaken under the superintendence of Mr. Bordman.

No ore seam of any value was discovered in either of the two localities. Smaller pockets of compact limonite were found accumulated in the surface of these rotten diorite masses, joining the schists, and in crevices of that rock, which evidently originated from secondary infiltration of iron solutions at the time the decay and disintegration of the diorite had already begun. The vicinity of the Ellwood mine is interesting, as we find at this place the before mentioned mica-schist series, succeeded by younger schistose deposits, interlaminated with banded, ferruginous quartz-rock seams and belts of graphite-schists, which group of beds corresponds with the lower strata of the Commonwealth mine, or the Florence mine, and with the large group of rock beds denuded in the test-pits near Keyes Lake, which have been described in the previous report. It is one of the rare instances in which the

superposition of the Commonwealth group on the mica-schists is clearly observable.

Quite large exposures of the mica-schist group occur in Sec. 27, T. 42, R. 32, and in the whole southeast quarter of this township; the greater part of the strata correspond with those exposed at the mouth of Paint River; certain beds are crowded with staurolite crystals and garnets and in the succession a large belt of a coarsely brecciated rock is observable, which incloses fine-grained, red colored rock fragments, consisting principally of orthoclase and quartz grains.

The strata in this locality are very much dislocated and dip in different directions. North of the exposures, not much over half a mile apart from them, project isolated hillocks of granite, and a half a mile west of them, separated by a drift-covered space, we find high bluffs of nearly vertically erected beds of the ferruginous quartz-schists of the Commonwealth group, which, from there, is the surface rock, without interruption onward to Chicagon Lake and Iron River.

Another very large complex of schistose rock beds, resembling to some extent the mica-schists of Michigamme, though not strikingly, occur in a similar relative position in the Gogebic district. The fine-grained groundmass of the schists in the Gogebic region is more of feldspathic than of quartzose nature, and the mica in them rarely prevails so as to give them as bright a lustre as those Michigamme schists have. They approach in their character almost as near to the Huron Bay slate-rock formation as to the typical form of schists on Michigamme Lake.

This schist formation which I observed principally near the south end of Gogebic Lake, had been previously described by me in connection with the magnetic actinolite-schists in Secs. 12 and 13, of T. 46, R. 42, which they conformably overlie, and needs therefore no repetition. The mica-schists in the Penokee region described by the Wisconsin geologists as staurolite-bearing, I have not had occasion to examine; those at the south end of Gogebic Lake, I think, contain nothing of this mineral.

CHAPTER VII.

KEWEENAW GROUP.

(A) GENERAL CONSIDERATIONS.

This immensely large succession of arenaceous and conglomeratic sedimentary deposits, interstratified with crystalline diabasic rock belts and with belts of porphyry, is peculiar to the Lake Superior region, and as it composes the entire Keweenaw Peninsula, this rock formation has been named after this landspur; otherwise it is also known as Copper-bearing group, as it forms the repository of an unusually great wealth in metallic copper.

The occurrence of large loose masses of copper, found in this region on the surface, or in the bed of rivers, was made known by the earliest travelers who visited it, and since that time this reported mineral wealth has attracted considerable attention to this land of promise. Particularly within the last fifty years the entire district has been searched over by explorers and by geologists, and became well known in its general geological features by the descriptions of these men; a great amount of more special information has been added to it daily, by actual mining operations undertaken in all parts of the district.

Under these circumstances, the report I give of the geological structure of this country, which I examined during the time of two summer seasons, does not, and can not pretend to be the result of original observations of myself exclusively; the greater part of it has to be a repetition of previously well known facts. But as by the miners constantly new discoveries are made, which have a bearing to elucidate points in geology, before not fully understood, the collection of this additional knowledge, together with the few advances in the conception of the natural history of this rock group, which I could make by my own efforts, I hope will do some good, at least in promoting information.

The topographical extent of this formation is in close relationship with the shape of the basin of Lake Superior. It forms, taken in its totality, a synclinal trough, the axis of which almost coincides with the longitudinal axis of the lake; a large portion of this rock formation must therefore be buried beneath the level of this great water basin.

Of the southern rim of this trough, on the shore of Lake Superior, not a trace is found east of Keweenaw Point, with the exception of the submerged cliffs of Stannard Rock, which consist of a reddish brown colored compact amygdaloidal rock, agreeing in its character with other trappean rocks of the Keweenaw series. Also, of the northern, southward-dipping rim of the trough, in the east part of Lake Superior, only a few isolated patches occur on the Canadian shore, or on islands near the shore, as on Mamainse Point and on Michipicoten Island.

The first larger development of this rock group is found recorded on the geological maps of Canada, at Nipigon Bay, Black Bay and Thunder Bay, where the formation is not confined to the shore part only, but extends far up to the north end of Lake Nipigon. The island, Isle Royale, belonging to Michigan, makes a part of this northern, southward-dipping part of the trough.

East of Thunder Bay, on the Canadian shore, older rocks representing the Huronian series, border the lake, but beyond the Canada boundary lines, south of the mouth of Pigeon River in Minnesota, the Keweenaw group occupies a broad belt, adjoining the lake all the way down to Duluth, dipping under moderately low angle to the southeast. From Duluth the extension of this group in a southwest direction has been ascertained to the head waters of St. Croix River, where it disappears under Silurian sandstones.

Wisconsin geologists inform us of the composition of the dorsal part of the Bayfield Peninsula by the Keweenaw group, dipping south and consequently representing a part of the northern rim of the synclinal trough. From the same source we learn the extension of a belt of the Keweenaw rock series from the head-waters of the St. Croix River parallel with the other, striking northeastward and dipping northwest or north. The inclination of the strata of this belt near the St. Croix being comparatively

flat, increases as we follow it eastward. At Montreal River, where the formation comes up to the shore of Lake Superior and enters Michigan, the ledges of it stand almost vertical. Thence, continued in eastern direction to the north part of Lake Gogebic, it gradually loses in steepness of its dip; the belt widens here considerably, composing the very broken country of the Porcupine Mountains. From Gogebic Lake an uninterrupted belt of the formation, striking in northeast direction, extends to the end of Keweenaw Point under the form of a prominent ridge, following the shore at some distance, and after crossing Portage Canal, occupying the entire width of the peninsula.

Another isolated range formed of the Keweenaw rock series, known as the South Copper Range, starts from the southeast end of Gogebic Lake and extends eastward for thirty miles. Farther east, in the valley of Sturgeon River, an outlier of the formation composes the so called Silver Mountain. The intermediate depressed space between the north and south ranges, drained by the west branch of Ontonagon River, and farther east by the Sturgeon River, is superficially covered with drift masses, but under the drift horizontal layers of Silurian sandstone seem to cover the entire area. The horizontal sandstones are, in many places, seen unconformably abutting against the foot of the brisk rock walls of the north range of the Keweenaw group, which present themselves on its south side, all along its extension from Gogebic Lake to Portage Lake. West of Gogebic Lake the Copper Range exhibits likewise brisk escarpements on its south side, but there the different members of the Huronian series are seen to underlie the Keweenaw group conformably, dipping northward with the same inclination.

The Huronian beds, in contact with the diabase belts of the Copper series, are not always the same, once lower ones, another time higher ones, which proves an erosion of the Huronian layers before they became covered with the diabasic overflows; but the conformity of these beds likewise proves that the Huronian rocks were, at the time, not much dislocated and that the upheaval of the incumbent and succumbent series must have occurred simultaneously at the end of the Keweenaw period. The obviously greater disturbance and corrugation of the Huronian strata, compared with the Keweenaw group, which latter is lifted in a

body without much distortion, indicates a more direct, immediate action of the disturbing forces on the Huronian beds, and a transportation of the pressure on the incumbent rocks, moderated in its impetuosity.

The disturbance of the Huronian strata did not occur everywhere in the same degree; the rocks in the Marquette region are infinitely more disturbed and broken up than the iron-bearing Huronian rocks in the Gogebic and Penokee Range.

Just the same happened with the Copper-bearing rock series, which, as before stated, near Montreal River stands almost vertical, at the Gogebic Lake dips under an angle of from 60° to 70°, at the Minnesota mine, and environs, about 50°. The same dip is observed at Portage Lake; further north it is 38°, at the Calumet mine, and near the end of Keweenaw Point, the dip of the beds is not much more than 30°,—often less.

It is also generally observable that in examining cross-sections through a large succession of strata on Keweenaw Point, the beds in the lowest position are much steeper inclined than those in the middle of the section, and these more than those on top of the series.

(1) STRUCTURE OF THE KEWEENAW GROUP IN GENERAL.

In the above introductory remarks the composition of this great succession of rock strata, of sandrock and conglomerate belts, with interstratified igneous rock masses, has been mentioned.

The opinions of geologists differ in their conceptions of the limits demarcating the Keweenaw group from the Huronian rock series.

In the Canadian reports of 1863, the very large succession of schistose, argillitic and quartzose beds, exposed as the underlying rocks of diabasic belts at Thunder Bay and other localities, is considered as the lower portion of the Keweenaw group.

But reading their own descriptions and those recently published in Mr. Irving's excellent work on Lake Superior rocks, I find, as the latter does, a perfect lithological resemblance of these schistose layers with the group of beds which occurs on the south shore of Lake Superior and constitutes the upper horizon of the Huronian series, without contradiction from any side. Of the identity of this lower rock belt of Thunder Bay, with the

upper Huronian rocks in Michigan, I became still more firmly convinced, after I had occasion to observe a continuation of this Thunder Bay series into the State of Minnesota, while crossing from Agate Bay to Vermillion Lake. The exposures observable on this route, do not only correspond with the descriptions given of the Thunder Bay series, but are at the same time a perfect counterpart of the upper Huronian of Michigan.

The conformity of this lower group of schists at Thunder Bay with the overlying series of rocks, which strata of the north shore have a much flatter dip than the corresponding series on the south shore, is in both compared regions not a perfect one, as we see lower or higher strata of the underlying group in contact with the incumbent diabasic rocks, which proves either an erosion or dislocation of the lower beds before they were covered with the others. Some interruption in the succession of rock ledges must have occurred at this period, as the entire complex of later formed strata has an essentially different lithological character from the earlier formed complex of beds, which among themselves again preserve a certain typical resemblance in contrast with the others.

The same divergence of opinions exists with regard to the upper limits of the Keweenaw group.

The large succession of horizontal sandrock beds found in contact with the Copper-bearing group on the east and on the west side of Keweenaw Peninsula is lithologically so similar to certain rock seams of the latter, that a distinction of both is difficult.

The eastern portion of these horizontal or only little inclined rock beds abuts unconformably against the Keweenaw rocks, which everywhere, as far as their extent goes, are in a more or less steep angle deviating from horizontality.

The western sandstones, identical in appearance with the eastern, and likewise almost horizontal, are also found in discordant position to the Keweenaw rocks, which is, for instance, quite obvious in comparing the strata of sandrock, composing the Apostle Islands, with the neighboring sandrock exposures, belonging to the Keweenaw series seen in nearly vertical position at the mouth of Montreal River, but on the west shore of Keweenaw, south of the entry into the canal, the western sandstones are largely exposed, having an inclination to the north-

west from 10° to 12° or less. The Keweenaw rocks cannot be seen in contact with them, as a space of several miles is between them, where no outcrop occurs; all is deeply covered with drift, but the first exposures we meet land-inward, are sandstones dipping under an angle of about 25° or 30° in the same direction as the sandstones on the shore; farther on, conglomerate beds follow and finally diabasic belts, all in conformable succession. Here a conformable succession of the strata in gradually diminishing inclination could with propriety be supposed to fill the interval, but we have no actual proof of it.

The equivalency of the eastern sandstones with the Potsdam sandstone group of New York is proved by fossils found in the upper layers of the series, east of Keweenaw, and south of it, in the Menominee region, where at the Breen mines and on the west side of the Quinnesec mines, certain seams of the horizontal sandrocks, overlying discordantly the iron-bearing series, are full of lingula shells and fragments of dikelocephalus and other primordial trilobite forms. The occurrence of the same fossils in the sandstones of St. Croix River, which are the upper beds of the western sandstone series, proves the identity of the eastern and western sandstones. The Silurian age of these rocks, formerly not generally accepted, is at present no more questioned, also their position above the Keweenaw rocks is by none disputed, except by Dr. M. E. Wadsworth, who asserts to have observed the superposition of the Keweenaw rock group on the eastern sandstone, which specified localities shall be more especially considered hereafter. An open question is yet, whether the Keweenaw group is a rock complex for itself, not connected with the Potsdam group by an uninterrupted continuity in the deposits, or whether it is only an earlier phase of the Potsdam period, in which these rock beds formed.

The general character and the succession of strata in this group in different parts of the Lake Superior region, is found described and illustrated by sections and maps in the reports of Jackson and of Foster and Whitney.

Prof. Pumpelly, while engaged by the Michigan Geological Survey for the examination of the Copper district, devoted his work principally to the examination of the Portage Lake and Eagle River districts, and published in the first volume of Michigan reports a great many detailed cross-sections and maps,

based on the records of the explorations made by the different mining companies; partly also such sections, with accurately measured distances, were the work of his own and his assistants. One of the largest of these, elaborated by Mr. Marvine, is the section from Eagle River to the Phœnix mine; it comprises a succession of about 8,000 feet of strata.

Comparing these sections made in different parts of Keweenaw Peninsula, it becomes obvious that certain beds identifiable by peculiar lithological characters, were persistent for long distances, and can serve as excellent landmarks for determination of the geological horizon of a locality, but as important as this is for general orientation, the widening and shrinking, and often total elimination of such belts, and the variations in the dip of the strata, cause so great differences in the relative distances from one belt to another, in different, more remote localities, that no scheme could be constructed guiding the miner reliably in his calculations to find, by measurement, the approximate position of certain beds he was looking for. Prof. Pumpelly attempted to calculate the approximate widening or shrinking of such rock belts in a certain direction, but, as could be expected, such calculations are extremely uncertain. Within limited precincts, however, environing a known, accurately measured cross-section, the miners have, with satisfactory results, used these sections as guides in their exploratory work.

The different mining companies, by continued exploration of their property have, in the course of time, considerably increased our knowledge of the structure of this rock formation, and daily new additions are made to it.

Of particular interest is the cross-cut made by the Calumet and Hecla Company. Starting from their productive conglomerate belt at the ninth level, they drove a horizontal drift at right angles with the trend of the formation to the boundaries of their property, a distance of 2,468 feet.

A similar grand enterprise, nearly finished, is the vertical shaft sunk on the Tamarack property, a half a mile west of the Calumet mine, in the expectation to meet with the conglomerate belt of the Calumet mine, which, if its dip remains as regular as it is in the mine, is calculated to be struck in a depth approximating 2,400 feet from the surface. The depth of this shaft was, on the 10th of July, 1884, 1,550 feet, and the work is

vigorously pushed ahead. After its completion we will have, adding the drift in the Calumet mine to it, an uninterrupted section a full mile in width. A special description of the strata intersected by these two monuments of human industry, will be subsequently found on another page.

The series of rock beds succeeding each other on Keweenaw Peninsula, without any indication of a repetition of the strata by folding, amounts to a surprising thickness, measuring by miles, and even single belts of the series, of sedimentary origin and little differing in material or molecular structure throughout their whole thickness, are found to be a mile in width. Moreover we see on Keweenaw Peninsula neither the lowest beds of the series exposed nor the highest; what we can see is not less than 30,000 feet of strata; in other regions the thickness of the group has been estimated by some geologists to be much greater.

On both sides of Portage Lake the sequence of strata is observable for the distance of about three miles, transversely to their strike, partly in natural exposures, partly denuded by the work of miners and explorers.

The strata on the two sides of the lake do not exactly correspond; according to Prof. Pumpelly, the north side is shoved 720 feet farther west than it had to be to correspond with the south side. The dip of the rock beds is to the northwest, under an angle of about 50° at Houghton; but further west, on Swede Creek, the sandrock strata of this group dip under an angle as low as 30°, and 25° even.

Proceeding from east to west, we find the lowest exposed beds in a ravine on the property of the Isle Royal Mining Company (T. 54, R. 33, Sec. 6, N. W. ¼), where an amygdaloid belt overlain by a belt of conglomerate, both steeply upheaved, comes in direct contact with horizontal ledges of Silurian sandstones, of which the entire lower part of the hillslope is composed.

The discordant contact of the beds is plainly observable in the bed of the little creek flowing through the ravine. From this locality, beginning on the north side of the just mentioned conglomerate belt, the Isle Royal Company had, about fifteen years ago, a row of trenches dug across the strike of the strata, through the whole width of their property, for the distance of almost a mile. The record of these explorations furnished by Mr. Mabbs to Prof. Pumpelly, was used by the latter in the construction of

the cross-section published by him, which, commencing in this place, was continued to embrace the entire succession of beds to the Atlantic mine, a distance of over three miles.

At present, most of these trenches are filled with rubbish, so that no occasion remains for re-examination of the details of the cross-section in this place.

In the alternation of beds, eight different belts of conglomerate occur on the Isle Royale property, none of which is very wide. The rocks intervening are dark colored, compact or amygdaloid diabases, differing some in various horizons, in grain and shade of color, but essentially they are only slight modifications formed of the same material; some of them belong to the lustre-mottled variety of diabases.

The amygdaloidal belts among the diabasic rocks, which are considered to be overflows of liquid lava streams, are no defined particular belts, but represent the foamy, porous portions of such lava streams, the cavities of which, by subsequent infiltration of mineral solutions, became replenished, partially or completely. The infiltrated contents of the amygdules are calcspar, quartz, laumonite, epidote, prehnite, analcite, datolite, chlorite or delessite and copper; sometimes only one of these minerals fills the cavity, but usually two or three of them together, whereby often it can be seen which of the minerals was first deposited and in which order the others were deposited. The quartz is sometimes in clear crystals; other times it forms a banded incrustation under the form of agate or chalcedony. The chlorite, or probably delessite, is likewise found under the form of an amorphous dark green mass, with dull fracture like tallow, or in radiated crystal concretions; this amorphous, soft, chlorite-like mineral is it which principally fills out the irregular interstitial cavities occurring nearly in all the compact masses of diabase, described by Pumpelly as pseudo-amygdules. It is often difficult to decide whether these pseudo-amygdules should be considered as secondary infiltrated substance or whether they were an original constituent of the rock, perhaps an alteration product of some other mineral which occupied the same irregular interstitial space.

The main constituents of all the diabases of the Keweenaw group are plagioclase and augite crystals, with addition of a smaller or larger quantity of disseminated magnetite granules and almost regularly of olivine. The plagioclase has often lost

its transparency, and also the augite and the olivine are often altered into a green turbid substance, or into a blood-red scaly micaceous, or other times dull earthy material. Other minerals found in the combination, of which epidote is very common, are likewise paramorphic products of the original constituents or secondary infiltrations. The amygdaloidal seams of the diabase belts, of which a great number were encountered in this section across the Isle Royale property, most all carry some copper, but only a few of them proved rich enough to pay mining them. Likewise did occur various transverse fissure veins, charged with copper ore in the form of chalcocite and whitneyite; the gangue mass is quartz and calcite and siderite, but of these also none was worth mining.

(2) SOUTH SIDE OF PORTAGE LAKE.

The Isle Royale Company has at present suspended all work in their mine. The same belt is running across the Grand Portage property and the Huron Company property, in both of which places the ore-bearing belt was mined long after the Isle Royale had quitted, but lately also the Grand Portage mine stopped work and only the Huron mine goes on, ostensibly with success.

On the Grand Portage mine another cupriferous seam, 200 feet west of the Isle Royale seam, was mined together with the other. The copper in these mines is not so often found in association with the brownish red colored amygdaloid, filled with calcspar and laumonite, as in a pale greenish, dull earthy-looking rock, sometimes compact and quite siliceous, other times porous, friable, mingled with calcspar and milky quartz seams. The greater portion of the metal found is in coarser masses, so called barrel-work, and also the stamp rock contains it in coarser form, so as to be washed without great loss. The width of the portion of this amygdaloid belt, or vein, to use the popular expression, which is taken out as the productive part, averages about twenty feet, sometimes less, sometimes more.

Examining from the Grand Portage mine westward, the same alternation of diabase belts, amygdaloidal and compact, with conglomerate belts or respectively sandrock belts, continues onward to the Atlantic mine, which is the mine situated farthest west.

According to the map of Prof. Pumpelly, between the Grand Portage mine and the Atlantic fourteen conglomerate belts occur, some of which are not over two or four feet wide, others twenty or thirty and two from fifty to one hundred feet.

Within the just described space, between the Grand Portage and Atlantic mine, a distance of two miles, a great many abandoned exploring pits and farther advanced mining enterprises are observable, and in most of them, examination of the material shows the presence of metallic copper, but the fact of their abandonment is sufficient proof that the work did not pay. On the road leading from Houghton to the Atlantic stamp mills, a large portion of this rock series is found well exposed naturally, or by cuts of the road, and by various old mining pits. Several amygdaloidal belts attract attention there; one on the Montezuma property, close to the west side of the large diabase belt cropping out at the lime kiln or the bridge, about thirty feet wide, superficially in decomposing crumby condition, consists of rounded and angular fragments of a purplish gray amygdaloid, its cavities filled with calcspar, with zeolites and in part with epidote, and of other fragments of pale green epidotic rock masses, all cemented into a breccia by an abundant light liver-colored interstitial mass of silico-feldspathic composition of fine grain, with smooth conchoidal fracture, which exhibits the lineated banded structure of a sedimentary rock mass; it enters the superficial cavities of the enclosed amygdaloid, in proof that these cavities in the rock were not replenished with other minerals at the time it became embedded in the cement.

On the west side of this brecciated belt follow for about 200 steps, compact, diabase ledges, with irregularly intermingled, streaky seams of epidotic character, insensibly merging with the dark colored diabase mass. Within this rock belt occur also amygdaloidal seams, carrying copper and bright greenish yellow epidote crystals as filling-material of the amygdules.

Mr. P. Gottstein's candle factory is established in the old excavations made by the miners in these amygdaloid seams, which were not found rich enough to continue the drifts further into the hillside.

West of this diabase belt occurs another amygdaloid belt about fifty feet wide. It has a dark, reddish brown color, full of unusually large, irregularly lobate and anastomosing cavities, filled

with laumonite or with the amorphous porcelain-like form of datolite, and is in a soft, crumby, decomposing condition, barren of copper.

A hundred and fifty steps further west, old test-pits are next to the roadside, in which a belt of similar brecciated rock masses is denuded, as the belt above described on the Montezuma property, but the rock is here fresh, undecayed and much harder; the color of the cement mass is greenish gray, instead of liver-colored; the laminated structure of the cement mass is very distinct.

Some distance further, in the bed of a creek which comes down from the Huron mine stamp mills, by the late disaster of the rupture of the dam of the reservoir of the stamp mill, the soil and rubbish were swept off clean from the bottom of this ravine, which offers at present a splendid opportunity to observe the irregular interposition of amygdaloidal breccia seams between compact masses of diabase. Both the diabase and the amygdaloidal seams sometimes intermingle, by interposition of wedgelike fragmental masses of one kind between the other. The amygdaloid breccia here has not the appearance of being the upper, foamy portion of any of the exposed diabase overflows, but is a shattered mass of a dark iron-colored, indurated mud, inclosing boulders of amygdaloidal and epidotic rock, and recemented by a network of seams filled with laumonite, more rarely with calcspar. The sedimentary origin of these belts of breccia is positively proved by the interlamination of regular sandstone beds between the brecciated rock seams. Most of the amygdules of the boulders in the breccia are also replenished by laumonite.

Among the diabase layers some have an amygdaloidal structure and the rather large cavities in them are replenished with the green, soft magnesian mineral, amorphous, steatite-like generally, but sometimes mingled with radiated concretionary nodules of delessite.

Between the creek and the Atlantic stamp mills, in four or five different places exploratory work has been done in belts of amygdaloid, interposed from time to time between rather coarsely crystalline diabase belts, but they were not high enough in copper to continue the mining.

Several conglomerate belts are also exposed within this space, of which the one next to the brewery is the largest. They all consist of mostly quartzless, red colored porphyry pebbles, some

of the size of a man's head; part of them are a compact crypto-crystalline felsitic mass, others are perfectly composed of red feldspar crystals with scaly masses of a dark green mineral scattered between, which under the microscope proves to be more or less altered hornblende. Less common in the accumulation of pebbles are such of a fine-grained dark diabase, in whose groundmass large crystals of red feldspar are segregated; also coarsely crystalline masses of olivine-bearing and hornblende-bearing gabbro are found among them.

The Atlantic mine, situated about one mile south of its stamp works, is opened in a large dark brown colored amygdaloid belt, overlain by a conglomerate belt fifty feet wide. This amygdaloid belt has in part the character of a breccia, composed of irregular larger and smaller blocks and rounded masses of a brown colored amygdaloid full of cavities, filled principally with calcspar and laumonite, but also quartz, prehnite, delessite, epidote and copper take part as filling-materials, either one alone or several of them associated, and of a cementing groundmass of the same brownish color as the inclosed amygdaloid masses, which exhibits distinct sedimentary lamination. The surface of the inclosed rounded masses of the amygdaloid is sometimes coated with a polished crust, streaky like slickensides; other times their pitted surface is shining as if glazed by exposure to fire.

The copper is quite unequally distributed in this rock belt; the richer portions of it are copiously interspersed with larger shotlike grains and also with branching hackly masses of the metal which have moulded themselves after the shape of pre-existing fissures and cavities in the rock; much of copper is also contained in the amygdules in association with the other mentioned minerals.

Other portions of the belt are poor and the copper contained in them occurs in smaller molecules. Practically no selection is attempted of the poorer rock from the richer, the entire width of the rock seam is taken out and the material run through the stamp mill, where as an average result three-fourths of a per cent of the rock mass is obtained in metallic copper. The working capacity of the stamp mill is so large that this small yield of metal still leaves a profit to the company.

The dip of the strata in the Atlantic mine is 55 degrees to the northwest. A large calcspar vein intersects the amygdaloid

belt in the mine, diagonally, which generally is not metalliferous, but occasionally on crossings with the amygdaloid, nests and pockets of metallic copper and of silver were enclosed by the spar.

I have yet to remark that the amygdaloidal cavities of the rock fragments in the breccia adjoining the interstitial cement are usually filled with this sedimentary substance, in proof that the cavities of the amygdaloid at the time of the inclosure of their fragments were empty. In the amygdaloidal rock instead of rounded secluded cavities, often also long cylindrical, somewhat strumose channels occur, many of them aggregated in parallelism and replenished with delessite, in the radiated crystalline, or in the amorphous steatite-like condition. Similar parallel tubular-amygdaloidal cavities often occur also in other localities.

West of the Atlantic mine a few more succeeding diabasic belts show themselves in outcrops on the rolling drift-covered plateau land, but these are the last known to occur in this direction; all the rock exposures from here to the west shore of Keweenaw Point are sandrocks or conglomerates, and even these are generally hidden under drift masses.

At the base of the hills west of the Atlantic stamp mills a large series of sandrock ledges, interlaminated with conglomeratic seams presents itself, dipping under an angle of about thirty degrees to the northwest; locally also a dip to the southwest is observable.

The lower, very coarse-grained sandrock beds have a brick-red color, as they consist prevailingly of red orthoclase grains with only a small proportion of quartz grains.

The higher strata are brownish gray micaceous, middling fine-grained sandstones in thinly laminated even flags; they amount to very great thickness. This upper series is best exposed in the valley of the creek running through the north part of Sec. 33. Farther on, along Portage Lake, no more exposures are observable on this side, but on the opposite side of the lake, in Secs. 27 and 28, and along Swede Creek in Sec. 22, this same series of sandrocks is extensively exposed, which localities I shall describe below, in connection with the strata of the Hancock side.

Among the twenty-two conglomerate belts, observed between the east end of the Isle Royale property and the Atlantic mine, in some of them a small impregnation with copper has been observed, but not enough to be of any practical value for the miner. But loose blocks of conglomerate have been found mingled with the boulder drift, equally rich in copper with the best rock of the Calumet mines. Whether these are carried from the north or whether they are parts of a conglomerate belt hidden under the drift in the vicinity has not been ascertained. Southwest of Houghton, on the east slope of the so called "Six-Mile" hill, by recent explorations, conducted under the supervision of Capt. Ryan of the Hancock mine, an amygdaloid belt, richly charged with mass copper, has been discovered and been traced for a length of 800 feet in undiminished richness. The copper is principally inclosed within sparry and epidotic fissure seams intersecting the amygdaloid belt in a network of branches; besides the small masses of copper, from a pound to more than a hundred pounds in weight, the seams contain also a considerable amount of chalcocite. The amygdaloidal rock itself contains only little copper; it is of brownish lilac color, quite hard and compact; the contents of its cavities are calcspar, prehnite and datolite. In the upper portion of the belt, about seven feet in width, the most of the copper occurs, but also lower down, within a space of 36 feet, enough copper is disseminated to be worth mining. The hanging of the amygdaloid is a reddish brown, compact diabase. Short distance south of the pits a conglomerate belt occurs. The shaft sunk in the mining locality was at the time of my visit ninety-five feet deep, and on both sides of it drifts are opened for the length of about twenty feet; then the work was suspended, as it was only calculated to show the value of the deposit, to bring the property into the market. The relative position of this ore belt is calculated to be about 1,000 feet east of the Isle Royale belt. From Ryan's mine, which is already on the southern side of the Copper Range, onward to Rockland, a great many old mining locations are found, many of them since years abandoned, others still working; these will be considered subsequently in connection with the description of the geological structure of the Ontonagon district.

3. NORTH SIDE OF PORTAGE LAKE.

On the north side of Portage Lake, opposite Houghton, the greatest part of the surface of the steep hillsides, rising to an elevation of 500 feet above the level of the lake, is deeply covered with drift deposits. Only few cliffs of rock present themselves at distances. The information we have of the succession of rock beds on that side is principally obtained from mines and mining explorations; some parts of the succession are therefore not so well known as would be desirable.

Commencing again, to examine from east to west, as we did on the opposite side, we find, of the part of the series composing the east half of the Isle Royale property, nothing disclosed owing to the above mentioned heavy drift accumulations spread over the surface, and for the want of exploring pits in that part.

In the supposed continuation of the epidotic amygdaloid belt of the Isle Royale mine we find the first foothold for comparison of the north side with the south side of the valley of the lake arm.

The Douglass mine, the Concord mine and the Arcadian mine have been working in this belt on top of the plateau lands some distance off from the brow of the hills, but since many years the places have been abandoned. The amygdaloid in these mines is associated with compact and porous epidotic rock masses as in the Isle Royale mine, which are principally the repository for the copper in coarse hackly masses, also considerable amount of quartz and calcspar makes part of the metalliferous seams; peculiar to these mines is the large amount of flesh-red orthoclase, replenishing not only fissures in the rock masses, but it likewise constitutes the filling material of the amygdules associated with the chlorite or delessite.

West or northwest of this rock belt for the distance of nearly a mile, no connected cross-section is observable. By test-pits the occurrence of four different conglomerate belts has been ascertained between the Douglass mine and the Pewabic mines. One of these conglomerate belts is exposed on the plateau a few hundred steps east of the tramway from the Franklin mine to its stamp mill. A second one, known as the North Star conglomerate, is denuded in test-pits of the North Star Mining

Company, near the quarter-post, between Secs. 18 and 19, T. 55, R. 33. The third belt is laid open in trenches dug by the Pewabic Company, about 900 feet east of the shafts of the mine, which received the name of Houghton conglomerate, and 400 feet farther west a fourth conglomerate belt occurs, believed to be a continuation of the belt mined at the Albany and Boston location. This belt is connected by a drift with the Pewabic mine, where from the seventy-fathom level of one of the main shafts a cross-cut has been made to the conglomerate belt.

The strata intersected by this drift are alternating seams of compact and amygdaloidal diabase.

None of the mentioned four conglomerate belts exceeds the width of from thirty to forty feet; they carry a small amount of copper, but not enough to be worth mining. The Franklin mine, Quincy mine and Pewabic mine are all opened in the same rock belt. Part of the copper is found disseminated through the mass of a brownish dark colored amygdaloid belt, the upper portion of which is the richest. Seven or eight feet next to the massive diabase belt in the hanging are taken out, which, going through the stamps, furnish about two per cent of washed metal.

A large additional quantity of copper in these mines is obtained in heavy masses, often many tons in weight, which are deposited into crevices of the amygdaloidal belt in association with calc-spar, epidote, quartz, prehnite, laumonite and sometimes with porcelain-like datolite masses. The copper rarely occurs in well formed crystals of its own form; it has generally shaped itself after the interstices left between the other minerals inclosing it, or it moulded itself into the form of one of these, which happened to be removed by lixiviation. The dip of the strata in the Quincy mine and the others adjoining it, varies between fifty and fifty-five degrees to the northwest. The hanging of these mines is formed by a wide belt of a dark colored compact, middling coarsely crystalline diabase. Under the microscope its components are found to be turbid plagioclase crystals, in intermixture with brownish colored augite, and an abundance of olivine grains in clusters, associated with magnetite, which latter, by higher oxidation and infiltration into the neighboring parts, tinges them purplish. Besides there are plenty of pseudo-amygdules composed of an amorphous grass-green magnesian

mineral, in which often radiated chlorite concretions are segregated.

In portions of this diabase belt, part of the feldspar constituent seems to be orthoclase of brick-red color, but not always these red colored crystals are orthoclase, as sometimes a dim polysynthetic striation is observable in them.

The amygdaloid of the Quincy mine has like most other amygdaloids a minutely crystalline structure, similar to the ashbed diabases, in which the augite is rarely seen in transparent crystals, but constitutes a turbid interstitial mass full of magnetite granules, in which colorless acicular plagioclase crystals are copiously dispersed. The magnetite is to great extent altered into sesqui-oxide, which tinges the rock reddish brown. The majority of the diabase belts occurring in the cross-section from the Isle Royale property to the Atlantic mine are olivine-bearing and many of the belts are lustre-mottled.

The lustre-mottled diabase associated with the Mabbs vein on the Isle Royale property is particularly rich in olivine; the same is the case with the diabase belt in the hanging of the Isle Royale vein.

The wide diabase belt exposed near the bridge at Houghton is likewise olivine-bearing, also the coarse-grained diabase in the mining pits on the Southside property, which is supposed to be the counterpart of the rock belt in the hanging of the Quincy mine, and a great many others, which seems to prove that olivine-free diabases are in the Portage Lake region not the prevailing type, as has been supposed by some.

About 1,000 feet west of the Quincy mine, another amygdaloid belt is worked for copper in the Hancock mine. The amygdaloid is dark brown, earthy-looking; its cavities are principally filled with delessite, laumonite and calcspar. The rock belt is much broken up and recemented into a breccia, which is intersected by a network of fissure seams filled with calcspar, prehnite, laumonite, in association with copper.

West of the shaft, exploring trenches have been dug across the property to its boundary lines, in which an alternation of compact and amygdaloidal diabases is laid open, besides two interstratified conglomerate belts and sandstone layers. A third conglomerate belt much wider than the two former, crops out a short distance farther west, then succeeds a large belt of

amygdaloidal rock with unusually large irregularly-shaped anastomosing cavities filled with chalcedonic and crystalline quartz with porcelain-like datolite and delessite. This belt is much shattered and recemented into a breccia by quartz and spar seams; it contains not enough copper to be of practical value. The three mentioned conglomerate belts are likewise cupriferous, but the amount contained is small.

The Atlantic mine and the Hancock mine are supposed to be opened in the continuation of one and the same rock belt, and a farther current supposition is, the identity of this belt with the so called Ashbed in the Eagle River district.

There is much similarity in the lithological character of the compared rock belts, but several other amygdaloids occupying different horizons resemble them as much; it requires, therefore, further proof to establish their identity.

On the west side of the above described amygdaloid, well exposed on the track of the Calumet R. R., a few more outcrops of diabasic rock belts are noticeable, but as in that direction no mining pits are opened and deep drift deposits are spread over the surface, I am ignorant of the succession of strata for an interval of not quite half a mile, when again exposures are found on the east line of Sec. 28, T. 55, R. 34. The first beds seen are very coarse-grained sandrocks of red color interstratified with seams of conglomerate; they consist principally of large grains of red feldspar and of a much smaller proportion of quartz grains and water-worn granules of diabase. Strike of the beds north-northeast; their dip northwest under an angle of thirty degrees. Next succeeding this large belt are fine-grained, gray colored, micaceous sandstones, splitting in thin, even flags, which layers are exposed in a belt a quarter of a mile wide, and retain, with little variation, the same character from one end of the section to the other. In the bed of Swede Creek the upper part of this succession of sandrock beds is finely exposed; west of this ravine all the land is covered with drift and nothing is known of the underlying beds between here and the western Portage Canal entry. This belt of gray, micaceous sandstones, is supposed to be an analogon of the group of arenaceous beds largely displayed in the Ontonagon district, and known under the name of Nonesuch mine rock series. It has been traced from Portage Lake northward to the

mouth of Hill's Creek. East of it occur in this part two very large conglomerate belts, one of them over a mile in width, which, if continued south to the Portage Lake region, must have very much attenuated, as the largest conglomerate belt seen there is not much over one hundred feet in width.

4. NORTHERN PART OF KEWEENAW POINT.

Proceeding to describe the structure of more northern parts of Keweenaw Peninsula, I take as starting point the west side of Torch Lake, following the courses of Hungarian Creek and Douglass Houghton Creek, in both of which creek-beds we ascend over a large succession of horizontal Silurian sandstones, until near the summit of the ravines we see them unconformably abut against the upheaved strata of the Keweenaw rock series.

This fact has been contradicted by Dr. M. E. Wadsworth, who pretends to have observed in these localities a conformity of the Silurian sandrocks with the Keweenaw rocks, whereby the latter would occupy the highest position and the Silurian sandstones be the underlying older strata. Ascending the narrow ravine through which Hungarian Creek comes down the hillside, forming on its way several cascades, we step over horizontal ledges of a red sandrock identical with the horizontal sandstone ledges exposed along the shore of L'Anse Bay, etc., until vertical rock walls nearly 100 feet high obstruct our progress. The creek leaps over them into the abyss. These high walls are formed of a large succession of horizontal beds of sandstone very similar to the ledges forming the bottom of the creek-bed below. Climbing to the top of the walls by a circuit and following the creek upward, we see the horizontal beds continue for some distance and find them to form several other abrupt offsets, causing cascades from fifteen to twenty feet in height; finally, near the summit of the hill, we observe another cascade about twenty-five feet high, caused by the projection of a conglomerate belt and an underlying belt of amygdaloidal rock, both of which are dipping northwest under an angle of about forty-five degrees, and right under the falls the horizontal ledges of sand-rock, which constantly had been under our feet up to this place, are seen in direct contiguity with the upheaved amygdaloid ledges. The sides of the creek-bed are covered with

loose rubbish and the contact is not visible there, but in the bottom of the shallow stream the unconformity of the sandrock ledges with the trappean rock belt is so fairly exposed that no misapprehension is possible. The sandstones, instead of dipping under the amygaloid, as Dr. Wadsworth thinks, have, if they are not altogether horizontal, rather a slight inclination in an opposite direction, away from the hill, and not toward it. The sandrock ledges forming the contact differ from Keweenawan sandrocks by an almost purely quartzose composition and a light color, white and red blotched.

At Douglass Houghton Falls the same relations between the Silurian and Keweenawan rocks exist.

Coming from the plateau on top of the hills, we see on it a large succession of compact and amygdaloid diabase belts intersected by the bed of the creek, which then at once tumbles over a precipice formed of an additional series of diabasic rocks near 100 feet in height; the dip of these beds is about forty degrees to the northwest.

Beneath this escarpment, a large body of amygdaloidal rocks in a much shattered condition, recemented into a breccia by sedimentary material, forms the bed of the creek. At the base of the rock bluffs forming the falls, a fissure vein is exposed which is filled with calcspar, prehnite, quartz, datolite, and carries some copper. A small drift following the vein for about thirty feet informs us that years ago miners tested their good fortune here and found themselves disappointed.

The brecciated soft and disintegrating amygdaloid mass forms the river bed for a short distance below the falls, then succeeds a large series of alternating beds of sandstones and conglomerates, which dip in the same northwest direction as the trap rock at the falls, and about under the same angle. These sandstones and conglomerates are in part very soft and friable; they are in part light whitish colored, composed almost exclusively of quartz grains and resemble the eastern horizontal sandstones. Other sandstone beds in the alternation are hard, dark reddish brown colored, and contain besides quartz granules also feldspathic grains and trappean detritus. The conglomerate seams are in part formed of densely crowded trappean, amygdaloidal, and porphyritic pebbles with sparingly interposed arenaceous cement; other times the main mass of such conglomerate is formed of a

quartzose sandrock with kaolinitic cement, in which pebbles are quite distantly scattered. The narrow belt of diabase, which, according to Dr. Wadsworth's statements, is found interlaminated with this group of sandstone and conglomerate beds, I was unable to discover, although I took special pains to find it.

Descending the creek, this very large succession of northwest-dipping arenaceous and conglomerate beds is seen for quite a long space, well exposed in the steep sides of the ravine, but then the layers begin to be broken up into an irregular mass of rubbish, pebbles, sandstone blocks and loose sand masses, intermingled without stratified arrangement.

After short interruption of the exposures of an orderly succession of beds, we observe, descending with the stream, first, in the bottom of the creek, light colored red and white blotched horizontal sandstone ledges, which soon, in the further descent, are seen to crop out in the sides of the ravine, and thence all the lower part of the hillside is formed of these horizontal layers, which, if not perfectly horizontal, instead of dipping forward to the hillside, gently dip away from it.

A gradual decrease of the dip as we descend the creek from the falls, which occurs according to Dr. Wadsworth's assertions, is not perceptible. The inclination of the northwest-dipping sandrock strata remains the same as far as they are exposed, then comes the girdle of loose rubbish, and the next appearing stratified rock ledges are at once in a horizontal position; the change is abrupt and the slight deviation of the beds below from horizontality is not in the direction of the beds above, but opposite,—anticlinal to them.

Relying on the northwest dip of the strata below the falls, I concluded they were lower sedimentary beds, belonging to the Keweenaw group, and was confirmed in this opinion by finding a short distance lower down the hillside, the horizontal sandstones in all regularity displayed. Considering only the lithological character of the northwest-dipping strata at the falls, I would not have hestitated a moment to identify them with the Silurian eastern sandstones, which, according to recent investigations of Prof. Irving, they actually are. The special explanation of this abnormal position of the eastern sandstones in the immediate proximity of the older Keweenaw rocks, and the undisturbed

condition of the beds some distance off from the contact, will be found in his own forthcoming report.

Similar irregularities in the position of the Silurian sandstone beds in the immediate vicinity of older upheaved rocks are recorded in the third volume of the Wisconsin reports.

This seems to prove that in the Lake Superior region, after the general disturbing forces had subsided, still in circumscribed smaller areas dislocations of the strata occurred. An instance of this kind presents itself fairly displayed for observation on the north shore of Bête Grise Bay, where we can see in various spots the steeply upheaved, northward-dipping rocks of the Keweenaw group in discordant contact with Silurian sandrocks, which latter in some places abut against the former in horizontal position, but more frequently we find them dipping southward, away from the trappean rocks, under an angle from thirty to forty degrees, while off from the contact line, on the shallow bottom of the lake, the dip of the strata becomes much flatter, and on the south shore of the bay their position has become perfectly horizontal. A detailed account of the rock outcrops along the shore of Bête Grise Bay will be given below in connection with the description of the Bohemian Range.

The horizontal Silurian sandstones are well exposed in a quarry on top of the incline of the railroad to the Calumet stamp mills; their position is not perfectly horizontal, but undisturbed sedimentary beds very frequently are not completely horizontal. Their contact with Keweenawan rocks is not visible. The first outcrops of these are noticeable about one-half a mile west of the quarry, where a large belt of quartz-porphyry is exposed by a cut of the railroad; it dips in steep inclination to the northwest. This quartz-porphyry is perfectly similar to the quartz-porphyry pebbles which compose the Calumet conglomerate. It is the only locality known to me on Keweenaw Point, where such a rock belt occurs; the porphyries of the Bohemian range are not of the quartziferous kind. Judging from its topographical position with regard to the Douglass Houghton Falls, this porphyry belt must belong to a lower horizon than the beds there.

Following the Calumet road from this place northwestward across the strike of the formation, we have, excepting the rock exposures in the creek above the Douglass Houghton Falls, no occasion to observe a larger connected cross-cut, until approach-

ing the Osceola mine, which is working an amygdaloid belt about 800 feet east of the Calumet conglomerate belt.

Here, by the work of the different mines, we are well informed of the order in the succession of rock beds; the Calumet mines made, as above stated, a cross-cut 2,468 feet long, showing the rock series south of the Calumet conglomerate belt, and by the Tamarack shaft other 2,000 feet of strata north of this belt will be disclosed within a short time.

This belt, about a mile in width, is the horizon within which most of the productive copper mines of Keweenaw point are situated. Several of the rock belts are recognizable by certain lithological characters and are found to be persistent for long distances, therefore can serve as excellent guides of the miner in his calculations where to meet with a rock seam he is desirous to find.

One of the most persistent beds is the so called Allouez conglomerate, which is traceable almost without interruption, from Portage Lake to the north end of the Keweenaw Peninsula. Its calculated vertical distance above the Calumet conglomerate is between 1,300 and 1,400 feet, measured from the Allouez mine southeastward; which distance of course is liable to vary considerably in different localities, as some beds shrink or widen and others become entirely eliminated or new seams are interposed. The Allouez conglomerate is never a very wide belt; forty feet is about its maximum thickness; often it is contracted to a narrow seam not one foot wide; locally it is richly impregnated with metallic copper, but in the greater part of its longitudinal extension the belt is barren of the metal, or at any rate, too poor to be profitably mined.

The conglomerate belt about 500 feet east of the Pewabic mine amygdaloid is considered to represent the Allouez conglomerate; from the Pewabic mine this belt is traceable without interruption through the Franklin, Mesnard, Dorchester and St. Mary's mining properties to the Albany and Boston mine, presently named Peninsula mine. On all these mentioned places, long time abandoned except the Peninsula mine, extensive cross-cuts had once laid open the succession of beds, particularly on the St. Mary's property. At present all these ditches and pits have caved in and are filled with soil and debris; for the detailed descriptions of these cross-sections I

therefore have to refer the reader to Prof. Pumpelly's report and maps, who had a chance to examine the exploring trenches when they were freshly opened, and could make use of the notes of the parties who did the work.

The first mining on the Albany and Boston location was done in the amygdaloid belt about 100 feet above the presently worked conglomerate belt. This amygdaloid is much broken up and recemented into a breccia by seams of calcspar, laumonite, prehnite and quartz; the same minerals are also the filling-material of the amygdaloidal cavities, besides epidote, delessite, analcite, orthoclase and copper. In the upper levels it was found to be very rich in the metal, but going deeper the copper lessened so much that work had to be abandoned.

The conglomerate belt mined at present has a width from fifteen to twenty feet; its pebbles are rather coarse; they consist principally of quartz-free porphyry of dark, reddish brown color, either with a compact, crypto-crystalline groundmass, or have a granite-like structure consisting of agglomerated red feldspar crystals with sparingly interspersed clusters of chlorite scales, associated with epidote. The copper is somewhat unequally distributed in the rock belt; the mined rock is therefore picked over before going to the stamp mills; still the amount rejected is not very large.

Four hundred and seventy-five feet northwest of this conglomerate a shaft has been sunk into an amygdaloid belt which is supposed to be the continuation of the copper-bearing rock seam of the Pewabic mine or Franklin and Quincy mines. It is locally well impregnated with copper, but for some reasons the mining of this belt has been suspended for several years.

In association with this amygdaloid occurs a very peculiar rock seam of porphyritic structure, which is impregnated with copper. There are two modifications: one is well laminated banded rock, resembling at a distance a coarse-grained sand-rock intensely red colored, with alternating lighter and darker seams, the ledge amounting to about two feet in thickness; the other is massive, deceivingly similar to a compact brown amygdaloid with densely crowded amygdules, but upon closer inspection the supposed amygdules are clusters of crystals with sharp ends, to which the inclosing groundmass has adapted itself; often also a granular mixture of quartz, epidote, copper

has partially or entirely replaced and moulded itself into the spaces formerly occupied by these crystals.

The dark, liver-colored, fine-grained groundmass of the rock, exhibiting a resinous lustre on fractures, consists mainly of a colorless quartz mass with copiously imbedded, laterally coherent, more or less minute crystalline molecules, intensely red colored by hematite, which seem to be feldspar. The laminated variety of this rock consists of the same dark, liver-colored groundmass disposed in layers of various thickness with interposed sheets of lighter red color, and the layers themselves are full of small crystals, originally feldspar but changed by paramorphosis into laumonite. The analogy of this porphyritic rock with the porphyries of the Bohemian Range is obvious, as the matrix of both is identical in material and many of their structural features perfectly agree. The strata exposed on the south shore of Keweenaw Point, in T. 58, R. 27, Sec. 30, especially deserve to be mentioned as similar in structure to the laminated form of the rock at the Albany and Boston locality.

On the Albany and Boston property is, 400 feet east of the productive conglomerate belt, another conglomerate denuded by trenches, which corresponds with the Houghton conglomerate found in the Pewabic mine location; it does not carry enough copper to be of value to the miner.

The next locality north of the Albany and Boston mine where actual work is done, is the Osceola mine in T. 56, R. 33, Sec. 26, N. W. ¼, which, as I have above stated, is opened in an amygdaloid belt about 800 feet east of the Calumet conglomerate, and, as the supposition is, over 2,000 feet stratigraphically below the Albany and Boston conglomerate belt, which is believed to be the same as the Allouez mine conglomerate, although a continuity has not been actually traced.

The Osceola amygdaloid belt is about thirty-five feet wide; it dips in conformity with the other strata under an angle of forty degrees to the northwest; its color is reddish brown, dull, earthy; part of it is soft, porous, other parts hard, compact; its amygdules are principally filled with calcspar, delessite, prehnite and epidote; sometimes also with quartz, datolite, etc. The copper in the rock is most found in a network of fissure seams traversing the amygdaloid belt in association with calcspar, prehnite, datolite, quartz and epidote, filling the interstices between these

minerals in hackly masses of smaller or larger size; sometimes the copper is found in druse cavities in very perfect, but rather small crystals; the spar crystals of such druses usually are bright red colored, being penetrated with an abundance of minute scales of copper.

The datolite, which in the Portage Lake mines occurs only in amorphous porcelain-like concretionary masses, is here found in large crystals of pale greenish milky color, but rarely obtainable with free ends, as the crystals are densely agglomerated and enveloped with calcspar and prehnite.

The hanging of the Osceola is a dark blackish colored, fine-grained diabase, which incloses in its linear fissures sheets of copper, and is locally throughout its entire mass impregnated with minute scales of copper. Thin sections exhibit a large proportion of olivine grains in its composition, besides the ordinary constituents, plagioclase, augite, magnetite and interstitial masses of the green chlorite or serpentine-like mineral, which likewise fills distant globular amygdules.

Some years ago, on the Osceola location, also the Calumet conglomerate belt was successfully mined, but the mine caved in and had to be abandoned. The work in this belt was not resumed, because the conglomerate in its southwestern extension on the property contracted and became almost barren of copper. On the adjoining Tecumseh location, where also a few shafts were sunk on the continuation of this belt, it was still found more contracted and contained little or no copper. Farther to the southwest this belt seems to be missing altogether.

In the hanging of the conglomerate belt at the Osceola location, a dark, fine-grained compact diabase belt occurs, which incloses irregular amygdaloidal rock masses rich in copper, most of it in coarser lumps,—so called barrel work. They use the old shaft in the conglomerate belt to come to this rock belt and work it to advantage.

The compact and the amygdaloidal rock are both olivine-bearing; the copper is principally found in fissure seams, associated with calcspar, prehnite and dark red orthoclase.

Under the superintendence of Capt. Daniell of the Osceola mine, the above mentioned deep shaft of the Tamarack location has been commenced in 1882 and has in the remarkably short time, up to July, 1884, reached a vertical depth of 1,550 feet.

A mapped record of the different strata sunk through in the shaft, which I received by the kindness of Capt. Daniell, is appended to this report,* to which I will add some descriptive remarks, concerning the lithological characters of the more important beds of this series. The shaft is located near the S. E. corner of the S. W. ¼ of the S. W. ¼ of Sec. 14, T. 56, R. 33; it first went through fifty feet of drift masses, then comes a belt of blackish colored compact diabase, fifty feet in thickness, beneath it a much narrower amygdaloidal seam, then another compact diabase belt, seventy-five feet wide, and again an amygdaloidal belt follows, and so alternately to a vertical depth of 460 feet, at which six belts of diabase and five of amygdaloid had been sunk through. Several of these amygdaloid belts were found well impregnated with copper.

At 460 feet from the surface a thin belt, only two or three feet wide, of a brownish red, very fine-grained jaspery rock occurs, which likewise carries copper. It resembles in its substance the homogeneous fine-grained pebbles of the conglomerates of the Keweenaw group. The very brittle rock is permeated in all directions by linear fissure seams filled with laumonite and calcspar or copper. Immediately beneath this belt succeeds a brecciated rock belt, forty feet thick, composed of dark brown colored, half decomposed earthy looking fragmental masses of partly compact diabase, cemented by an abundance of calcspar and laumonite seams, which are remarkably rich in copper interwoven with the sparry crystal aggregate, or also in heavy masses, many pounds in weight, imbedded between them. The foot wall of this cupriferous rock stratum is formed by a dark blackish colored fine-grained diabase belt, 170 feet thick, in its oblique intersection, which by its jointed structure, on exposure or by the stroke of a hammer, falls into small irregular sharp-edged pieces, the surfaces of which are covered with a smooth shining slickenside coating, consisting of a dark green, semi-transparent, soft, lubricous, delessite-like mineral and intermediate between these slickenside rock joints most generally a thin sheet of copper is found deposited, varying in thickness from that of the artificial leaf gold to sheets one-eighth of an inch and more

*[In place of the above record I have substituted geological columns of the North Tamarack shafts, Nos. 3 and 4, complete to Jan. 1st, 1894. These records are due to the courtesy of Capt. Daniell, and of Prof. R. M. Edwards, the Mining Engineer of the Tamarack company.—L. L. Hubbard.]

in thickness. The amount of copper found in this rock is larger than I have seen it in any other compact diabase rock. Under similar circumstances sheets of copper occur in the diabase forming the hanging of the Osceola amygdaloid, and in that in the hanging of the Calumet conglomerate belt. At the vertical depth of 670 feet, the shaft strikes a conglomerate belt from three to four feet in thickness, which is supposed to be the equivalent of the Allouez conglomerate; it is well impregnated with copper in coarse hackly masses, its porphyritic pebbles are soft, decomposing, and the interstitial cement is calcspar, in intermixture with chloritic mineral and laumonite; parts of the belt are also formed of a fine-grained, laminated sedimentary mud mass of deep reddish brown color, variegated by intermingled greenish colored streaks. The next lower 200 feet are almost entirely of amygdaloidal character, with a few interposed narrow seams of compact diabase. They are comparatively poor in copper. A portion of the amygdaloidal rocks is very hard, with a sort of vitreous fracture; another portion is soft and in progress of decomposition. The amygdules are mainly replenished with calcspar, laumonite, delessite and some quartz.

From the depth of 900 feet to 1,330, four rather large, compact belts of diabase alternate with three narrower amygdaloidal belts, the lowest of which is of a brecciated structure. At the depth of 1,341 to 1,357 follows an amygdaloid belt, from there to 1,409 compact diabase, then amygdaloid to 1,424, which latter carries copper and is partly a dark purplish colored earthy-looking conglomeratic mass, intersected by spar and laumonite seams, partly a very compact dark gray colored rock, with calcspar and epidote amygdules, some of it shattered and firmly recemented into a breccia by epidotic seams. From 1,424 to 1,495 compact diabase, then 15 feet of amygdaloid and from 1,510 to 1,550 a fine-grained reddish brown colored compact diabase, which was the bottom rock of the shaft on the 10th of July, 1884.

Nearly all the different compact diabase belts occurring in the shaft, in thin sections exhibit a lustre-mottled structure; the light colored areas are almost exclusively composed of transparent plagioclase crystals, intermingled with pale yellowish brown very fresh augite; in the surrounding dark colored, interstitial area, very little augite is found associated with the plagioclase, but instead of it abundant clusters of a red colored, micaceous

mineral (rubellan?) associated with agglomerations of magnetite granules and with grains of olivine, of which latter the delicately laminated, micaceous mineral seems to be a paramorphic product. The red color does not seem to be essential to it, as portions showing the same laminated structure are almost colorless. Seen vertical to the cleavage, they are not dichroic, but distinctly so if the light enters parallel to it. In all of them, numerous pseudo-amygdaloidal interstitial spaces are replenished with the often before mentioned amorphous or radiated crystalline steatite-like mineral of pale or darker green color.

Another similarly interesting exploring work has been shortly finished by the Calumet and Hecla Company. In order to learn the succession of rock beds on their location, southeast of the conglomerate belt, they ran a drift from the ninth level of shaft No. 4, of the Hecla mine, beginning at the foot-wall of the conglomerate, and carried it at a right angle to the strike of the formation to the limits of their property, a distance of 2,463 feet.

Mr. Wright, the agent of the mine, had the kindness to furnish me with a copy of the mapped record of this drift, which is appended below.*

We observe on it the intersection of ten different amygdaloid belts, with intervening much wider belts of compact diabase. At the distance of 1,571 feet from the Calumet conglomerate, another conglomerate belt, 44 feet wide, is intersected, which has been identified as the prolongation of the conglomerate belt on the Kearsarge mining property, which, on the Ahmeek location has been mined for copper, but has been abandoned again, the copper being too unequally distributed through it. Locally, the belt was found to be quite rich.

Several of the amygdaloid belts, intersected by the drift, were found sufficiently cupriferous to be worth mining, but for the present no effort was made to do any work in them, as the conglomerate belt gives sufficient employment for all their laborers. Among these the fourth belt from the conglomerate, the so called Osceola amygdaloid, is the most promising. The conglomerate belt of the Calumet and Hecla mine averages a width from 12 to 25 feet; its dip varies from 36 to 39 degrees to the

[*Through the courtesy of the present management, I am able to append a new copy that shows several sections in different parts of the mine not opened up at the time the above was written.—L. L. HUBBARD.]

northwest. Fully two miles of the length of the belt are on this mining property; the deepest shafts following the inclination of the belt are 2,700 feet long, which makes a vertical depth of about 2,068 feet below the surface. On the entire extension of the property, the conglomerate belt has very few barren spots, and the rock is, without selection, sent to the stamp mills where it yields about five per cent of washed metal; portions of the rock are much richer, as high as thirty per cent in metal. The product of the mines during the last three or four years was about 16,000 tons of ingot copper annually.

The conglomerate of this belt is reddish brown colored, hard and compact; locally composed of rather large, rounded pebbles, but the main mass consists of smaller pebbles with many little-worn, angular rock fragments among them. The interstitial material consists of smaller arenaceous particles held together by siliceous and calcareous cement; the copper in the rock occupies mainly these interstitial spaces between the pebbles, and is sometimes replacing the cement altogether.

The union of these fragmental masses is very firm, a stroke of a hammer does not sever their connection, but breaks the mass straight across the pebbles, which, with the exception of a small proportion of diabasic and amygdaloidal boulders are all of porphyritic nature but quite variable in molecular structure. A large portion of them consists of a reddish brown, compact, homogeneous, silico-feldspathic substance, with smooth, conchoidal fracture. Others inclose within the same aphanitic groundmass well formed, larger crystals of feldspar, of red or whitish color; in still others, which are often more abundant than the others, the dark reddish colored, compact groundmass incloses, besides feldspar crystals, a great number of rounded transparent, colorless grains of quartz which, on fractures, give a blackish reflex. Other pebbles have none of the amorphous groundmass; they consist of a granite-like agglomeration of interwoven red feldspar crystals, with scarcely any other component, or else this same crystalline, feldspathic rock mass contains copiously interspersed quartz grains, besides scattered blackish colored molecules which sometimes are recognizable as altered hornblende crystals or as biotite scales, but often are a shapeless, earthy-looking remnant of a decomposed mineral, not to be determined. These rocks

could, with propriety, be classed with granite, but they are allied with the before mentioned porphyries by transitory forms which are not completely crystalline, but have a scanty interstitial groundmass analogous to the groundmass of the porphyritic kind.

I have stated above that the copper occupies, in the conglomerate, the interstitial spaces between the pebbles and often takes the place of the previously existing arenaceous cement. Rarely the copper had a chance to enter the substance of the pebbles through capillary fissures imperceptible to the eyes before the pebble is fractured, but sometimes the same altering influences which removed the interstitial arenaceous material, replacing it by calcspar, epidote and copper, affected also the larger pebbles; they made them first porous and discolored and finally changed them into an epidotic mass permeated with a spongeous skeleton of copper in association with more or less calcspar. Such altered pebbles, some of them as large as a man's head, quite frequently occur at the Calumet mine, and also sometimes in the conglomerate of the Albany and Boston mine. In some instances the copper has almost entirely replaced the material of such pebbles and forms solid, ponderous masses in the shape of the pebble, other times the change was not perfect, and the spongeous copper skeleton inclosed within its cavities yet unaltered crystals of orthoclase and quartz grains enveloped by a mealy chloritic and epidotic crust.

Prof. Pumpelly first gave notice of the occurrence of such copper masses in pebble form and suggested their paramorphic origin by replacement of the material of the decomposing porphyry pebbles.

The conglomerate of the Calumet mines frequently incloses seams of a fine-grained, well laminated sandrock, exhibiting ripple marks on the surface of its layers, and locally such beds are richly impregnated with copper. Like in all the sandrocks of the Keweenaw group, the feldspar grains overbalance the quartzose grains in the rock mass. The hanging of the Calumet conglomerate is a dark colored, fine-grained diabase, which, like the above mentioned diabase belt in the Tamarack shaft, 500 feet below the surface, has a jointed structure, with the cleavage seams coated over with a soft, chlorite-like mineral in slickenside fashion, holding between themselves sheets of copper from

the thickness of tissue paper to that of a knife blade and sometimes six or eight inches square; likewise are cloudy patches in the solid mass of the diabase disseminated with an abundance of scaly molecules of copper, but the miner considers the amount of metal too small to pay any attention to its collection. In association with the compact diabase in the hanging, amygdaloidal rock masses occur, whose amygdules formed of calcspar, laumonite, quartz and delessite, often contain a considerable amount of copper.

I have previously mentioned that the Calumet conglomerate thins out and is almost destitute of copper in its extension south of the Osceola mine, and soon after entirely disappears. The same is the case in its extension northeast of the Calumet mine, on the Schoolcraft mining property, where extensive work has been done in this belt, but the large burrows of waste rock, in which no copper can be detected, show that the Calumet mine struck an extraordinary rich spot and that locally this belt is almost barren of the metal. The work in this conglomerate on the Schoolcraft mine is long time suspended, but on the Osceola amygdaloid belt, which likewise intersects the property, mining has been continued until late. Farther to the northeast the continuation of the Calumet conglomerate belt has been traced only for a short distance; it was found to be much narrower and poor in copper.

In the mines on the south side of the so called Greenstone Range, a cupriferous conglomerate belt, holding approximately the relative stratigraphical position of the Calumet conglomerate, has been identified with it, but it is not positively ascertained whether this is a continuation of the same belt or not. A half mile northeast of the Schoolcraft mine a new mine, called the Wolverine mine, has recently been opened in an amygdaloid belt, 2,865 feet east of the Calumet conglomerate, or 1,250 feet east of the Kearsarge conglomerate.* The location is on the N. ½ of the N. E. ¼ of Sec. 17, T. 56, R. 32.

[* Inasmuch as several changes of Dr. Rominger's figures had been made in the type-written copy of his manuscript, before the latter came into my hands, I take the liberty of inserting here several measurements made a number of years ago by Mr. James Crawford, and kindly furnished me by Fred Smith, Esq., agent of the Allouez mine, who vouches for their substantial accuracy. They are as follows, to wit:

On the Kearsarge location,—

Allouez conglomerate to Calumet and Hecla conglomerate, 2,050 ft.
Calumet and Hecla conglomerate to Kearsarge conglomerate, 1,500 ft.
Kearsarge conglomerate to Kearsarge amygdaloid, 1,250 ft.

—L. L. HUBBARD.]

This belt is unusually rich in copper. It is a dark purplish brown rock, with dull earthy fracture, harder or softer, much shattered into fragments, which are recemented into seams of calcspar and of orthoclase in association with quartz, epidote and delessite. The amygdules are filled with laumonite, epidote, delessite and calcspar, usually several of them associated; in some parts of the rock the amygdules consist nearly all of a dark green amorphous serpentine-like mineral. Much of the amygdaloidal belt is transformed into a light green porous epidote rock, which principally carries the copper in ponderous hackly masses, so called barrel-copper. Near the surface the copper is much oxidized, coated over with red oxide, malachite and azurite. The same amygdaloid belt is laid open by numerous test-pits in the adjoining Kearsarge property.

The foot-wall of the amygdaloid is a coarsely crystalline, dark colored diabase belt, about 100 feet wide. It projects in a row of bluffs, at the base of which a belt of sandstone and conglomerate ledges crops out. The foundation of the stamp mill rests on this sandrock, which is probably the equivalent of the so called Kingston conglomerate. East of it are outcrops of compact diabase, but the natural exposures in that direction are much interrupted and no explorations of the ground had been made, by which the farther succession of underlying beds could be studied.

One mile north of the Wolverine mine is the Allouez mine, from which the often before mentioned Allouez conglomerate received its name.

Measurements made from the mine across the trend of the formation southeastward show the horizontal distance from the Allouez conglomerate to the Kearsarge conglomerate to be 3,810* feet, or reduced to vertical thickness of the intervening ledges 2,647 feet.

At the Allouez mine the strata dip under an angle of 37 degrees to the northwest. The thickness of the conglomerate belt is from 20 to 25 feet; it resembles the Calumet conglomerate with regard to the nature of the pebbles composing it, but they are generally of larger sizes. The copper in the rock is unequally distributed, and much of it has to be rejected. The average yield of the rock sent to the stamp mills is not much over one per cent of washed metal.

[* See foot-note on preceding page.—L. L. H.]

Beneath the conglomerate various coarser and finer-grained compact diabase belts are well exposed on the mining property. The hanging of the belt is a blackish colored, very fine-grained rock; part of it is lustre-mottled; it consists of a mixture of clear, prismatic crystals of plagioclase with about an equal quantity of pale brownish transparent augite, besides a good proportion of olivine grains which superficially are altered into a turbid crypto-crystalline, greenish substance; the magnetite in the rock is partially altered into red oxide. This rock is the equivalent of the lustre-mottled rocks forming the base of the bluffs at the Cliff mine and along the entire extent of the Greenstone Range.

The succeeding higher strata at the Allouez mine do not project in so steep escarpements as at the Cliff mine, and further to the northeast they are also not exactly alike with them in lithological character, but in the conglomerate belt, which from here can be traced almost without interruption to the northeast end of Keweenaw Point, we have a sure index of the geological horizon.

The rock belts on the north side of the conglomerate are very well exposed. Above the dark, fine-grained, partly lustre-mottled rock in the hanging, which amounts to about 100 feet in thickness, an alternation of amygdaloidal seams with compact and pseudo-amygdaloidal diabase belts succeeds in a belt a half mile wide, almost without an interruption of the outcrops. The relation of the amygdaloidal portions to the compact portions of a belt is here finely disclosed; we observe here that the amygdaloidal belts are not separate overflows, but constitute merely the upper portion of the compact belts; often also the amygdaloidal masses are intermingled with the compact rock in narrow bands and in lenticular masses wedging out at both ends; these bands and secluded lenses of amygdaloid are generally very hard, fine-grained, with a flinty fracture.

The northern strata have the fine-grained porphyritic structure of the so called Ashbed diabase; the Ashbed itself is not observable, as on the place where it should be expected the surface begins to be covered with drift. Short distance beyond this drift-covered space, at the location of the stamp mill, the large conglomerate belt is seen exposed, whose continuation at Eagle River is a mile in width, and probably would also here not be found narrower if it was better denuded.

A mile northeast of the Allouez mine the Kearsarge conglomerate has been worked for copper at the Ahmeek mine. The belt has here a thickness of 60 feet, consisting in part of well laminated fine-grained sandrock ledges, in part of conglomerate layers. These latter differ from other conglomerates of this group by the dark, blackish color of their cement and by the prevalence of sharp angular, rather small fragments, over the rounded water-worn pebbles, most of which are a dark brownish, red colored quartz-porphyry. Some portions of the rock are very rich in copper, but only in patches; the remainder of the belt is poor or contains no copper at all; the mining has therefore been discontinued.

The hanging of the conglomerate is a black colored, middling fine-grained diabase, consisting of transparent plagioclase and augite crystals, besides numerous clusters of olivine grains more or less altered and associated with an aggregation of magnetite granules.

The foot-wall of the conglomerate is a coarsely crystalline pseudo-amygdaloidal rock of reddish gray color, consisting of turbid plagioclase crystals, of reddish brown, non-transparent augite and of disseminated clusters of magnetite; the interstitial pseudo-amygdules are filled with calcspar and with the green, serpentine-like mineral inclosing radiated, concretionary masses of delessite.

North of the Ahmeek mine, on the road to the Cliff mine, a number of abandoned mines are found at the base of the Greenstone Range, which from here to the end of Keweenaw Point forms a conspicuous chain of high mountains with brisk escarpments on the south side.

All the before described mines were opened in beds parallel to the stratification; from here northward we find, with few exceptions, only transverse fissure veins mined. The discovery of such transverse seams, filled with a rock material obviously different from the surrounding wall-rock could readily be made in the mural rock escarpements, and the large amount of copper found in many of them directed the attention of the miner in this part of the country principally to them, although many of the amygdaloid belts were cupriferous, some sufficiently rich to be successfully mined.

As a rule, these fissure veins were found to contain little

copper, while intersecting the compact masses of the diabase, called "greenstone" by the miner, but became particularly rich in the metal during their intersection of the softer porous amygdaloidal belts. Frequently, from the transverse vein the miner drifted sideways into such amygdaloidal beds, finding them rich enough to remunerate for the work.

Much of the copper in the veins is found in large masses, some many tons in weight; quite often also silver is found in association with the copper. The Cliff mine is the oldest and most widely known mine in this part of Keweenaw point, once very successful, but since a good while very little worked, and at present left idle. The fissure vein which it followed was naturally exposed in the bluffs and is yet observable from the valley below, as the portion in the higher part of the bluffs was not touched by the miner. In this outcrop we see not a single larger fissure filled with vein matter, but a great many sub-parallel smaller fissures, in reticulated connection with larger segments of wall-rock between, or in the wider parts of the vein the cleft was evidently first loosely replenished with debris of the wall-rock tumbled into it, which subsequently became cemented into a breccia by infiltration of the different mineral solutions which deposited the so called vein matter. The minerals constituting it principally are quartz, prehnite, calcspar and laumonite; more subordinate is the occurrence of analcite, apophyllite and various other zeolitic minerals, besides orthoclase, datolite, etc. The copper in various modes associated with these minerals is evidently, like them, deposited from a solution of copper, most likely by galvanism. It penetrates the other minerals in finer reticulated films or in delicate leaflets, or it has adapted itself in coarser masses to the interstices left between the other minerals; more rarely it formed in druse cavities and could then develop itself in its own crystalline form in manifold modifications, which are highly esteèmed by naturalists and more so by the tribe of curiosity hunters which sometimes offer fabulous prices for them. The large masses of copper are generally found embedded in calcspar associated with laumonite, prehnite and epidote. As the vein of the Cliff mine was found not to contain much copper within the massive rock belts which form the higher part of the bluffs, it was followed into the underlying deeper strata which dip under an angle of 30 degrees to the north-

west. The strike of the vein is almost at right angles to the trend of the formation and its position is little deviating from the vertical.

From the maps of the mine we learn that about thirty different strata of alternating compact and amygdaloidal diabase belts have been sunk through in following the fissure vein downwards from the base of the Greenstone bluffs, where a narrow sedimentary seam, the so called "slide," represents the Allouez conglomerate belt. The deepest levels are about 1,600 feet below the top of the Greenstone bluffs; the farthest shaft, No. 2, is about 1,750 feet south of the bluffs, its depth is 400 feet, and, according to the calculation of the dip of the strata, the northern shaft, 1,600 feet deep, is about on the same stratum as shaft No. 2, 400 feet in depth.

Various of the amygdaloidal belts met with in mining the fissure vein were found so rich in copper, that drifts were sideways driven into them at different levels, and the last work done in the mine by tributors was in these side-drifts. Three years ago, Mr. Brockaway, the agent of the mine, made extensive explorations south of the old shaft of the Cliff mine, using the diamond drill and giving it a direction so as to intersect the strata vertically to their bedding. The drill holes are not all located in a straight line, but their relative distances southward were determined by measurement.

The first drill hole is 750 feet south of shaft No. 2; its depth is 148 feet. The rock beds intersected were as follows: First, an amygdaloid belt carrying some copper, then a blackish colored compact diabase. At the bottom of the hole a thin seam of a reddish colored jaspery rock was struck, which is 1,290 feet vertically beneath the base of the Greenstone bluffs. The miners consider this jasper belt as the equivalent of the Calumet conglomerate.

A second drill hole, 365 feet deep, is 750 feet south of the former; it intersects five belts of alternating amygdaloidal and compact diabase layers.

Three hundred and twenty-five feet south of the latter drill hole, a shaft has been sunk to the depth of 65 feet, which is supposed to intersect the second diabase belt and the third amygdaloid belt of the former drill hole. The amygdaloid is rich in small masses of copper, its vertical distance from the

jaspery seam, believed to be the Calumet conglomerate, is 532 feet, and the identity of this belt with the Osceola amygdaloid is suggested.

A second shaft, 125 feet deep, is sunk 500 feet south of the other, 700 feet east of the northwest section corner of Sec. 6, T. 57, R. 31, which is supposed to penetrate the fourth diabase belt and the fifth amygdaloid belt of the last diamond drill hole. At the same time it is sunk on a fissure vein, six feet wide, which carries a fair amount of copper in small masses, associated with calcspar, prehnite and quartz.

One thousand feet south of this deeper shaft, another drill hole commenced in a massive diabase belt, then succeeded an amygdaloid, and so four times in alternation to a depth of 260 feet, where a conglomerate, about two feet wide, occurred, which is thought to represent the Kearsarge conglomerate. The vertical distance of this conglomerate from the above mentioned supposed Osceola amygdaloid, is 810 feet.

Two hundred feet farther south a drill hole, 361 feet deep, penetrated below the conglomerate, first, an amygdaloidal belt, then compact diabase.

Three hundred and twenty-five feet south of this, another drill hole, 328 feet deep, commenced in the diabase belt next above the conglomerate and intersects, besides the amygdaloid and diabase belt penetrated by the former drill hole, another amygdaloid and underlying diabase belt.

Six hundred feet south, another drill hole, 266 feet deep, went through various modifications of diabase.

Three hundred feet south of this, by boring to a depth of 296 feet, several alternations of compact and amygdaloidal diabase were struck beneath a thick cover of drift deposits.

The last of the drill holes, 300 feet south of the former, went all through drift, barely touching the solid rock at the bottom.

The total of the explored ground south of the bluffs of the Cliff mine comprises 2,632 feet of strata, measured vertically across their bedding. A continuation of this cross-section northward, from the base of the Cliff mine bluffs to the lake shore at Eagle River, a distance of over two miles, is given by the accurately measured cross-section from the Phœnix mine to Eagle River, prepared by Mr. Marvine and published in Prof. Pumpelly's report, to which the reader is referred. We learn

from it the thickness of the rock complex composing the Greenstone Range proper, to amount to about 1,500 feet of strata. The lower beds are dark blackish colored, rather fine-grained; most of them have the peculiar structure described by Prof. Pumpelly as "lustre-mottled," which structure, however, is observed in a great many other Keweenawan diabase belts in higher and in lower horizons. The strata forming the top of the bluffs and a number of other succeeding diabase belts are coarsely crystalline, some darker, others lighter colored, but in composition the entire complex of beds composing the Greenstone Range differs very little; they all consist of transparent plagioclase and augite crystals (which latter have in their sections a pale yellowish brown color) in intermixture with a variable proportion of olivine and magnetite grains, which both are frequently clustered together. The plagioclase is in some of the rock belts partially turbid, the augite has rarely suffered much alteration, but the olivine is almost regularly peripherically altered into a green, minutely crystalline substance, or else a purplish, brown colored area surrounds the olivine grains. Not uncommon in the coarsely crystalline variety of the rock are pseudo-amygdules replenished with the soft green, serpentine-like mineral which enters into the composition of almost every diabase of the Keweenaw group. In the upper horizon of the just described complex of rocks, next to a fissure vein once worked by the *old* Phœnix mine, a very coarsely crystalline red and black speckled diabase belt occurs, in which red orthoclase seems to have taken the place of the plagioclase, but on examination of thin sections these turbid crystals frequently show yet a dimly marked polysynthetic striation, and most likely all of them are plagioclase crystals altered by a cloudy infiltration of ferruginous pigment. The augite is partially altered into chlorite, but some of the crystals are perfectly fresh and translucid. This rock encloses also a large number of colorless apatite prisms. A very similar rock occurs at the Mendota mine near Lac La Belle, which evidently occupies an entirely different horizon in the series. North of this group of coarse-grained diabases, the so called greenstones follow, a wide belt almost exclusively formed of diabasic rocks, which amounts in the aggregate to a thickness of 2,000 feet. Most of these are quite fine-grained, rather dark colored, and often porphyritic by

segregation of larger feldspar crystals within the fine-grained groundmass; the compact belts alternate with amygdaloidal seams, of which one is particularly to be mentioned as being cupriferous, the so called Ashbed of the miners. This belt is quite large, locally from 50 to 150 feet wide; in many places along the west shore north and south of Eagle River we find mines opened on it, but with the exception of the Copper Falls mine, all others are presently abandoned; the *old* Phœnix mine in former times worked in it extensively.

North of the Ashbed, which is overlain by a thick belt of compact, fine-grained diabase, speckled by segregated larger plagioclase crystals disseminated through the dark gray groundmass, succeeds another complex of rocks, amounting to about 1,200 feet of strata.

In the previously described series, amounting to a thickness of over 3,500 feet, sedimentary layers were excluded, with exception of some seams connected with the Ashbed, while in the group presently under consideration, numerous sedimentary rock seams are found to alternate with the diabasic rock belts. In Mr. Marvine's section we see not less than ten sandrock and conglomerate belts interstratified within the space north of the Ashbed and south of the large conglomerate, almost a mile in thickness, which forms the shore part of the land near Eagle River village. The diabasic rock belts intervening have nearly all an amygdaloidal structure; most of them are middling fine-grained, but also coarser crystalline seams occur, as for instance, the uppermost bed underlying the great conglomerate at the cascade near Eagle River village. Various of these amygdaloidal rock seams are copper-bearing, but so far the miner has paid little attention to them.

The lowest beds of the great conglomerate belt which terminates the Eagle River cross-section, are fine-grained sandrock beds inclosing distantly scattered pebbles; 60 or 70 feet above the base coarse conglomeratic strata succeed which in the ascending cross-section presented in the river-bed are frequently interposed again with seams of red colored sandrock. The pebbles composing the conglomerate are in the majority formed of different varieties of red colored porphyry; a part is homogeneous, fine-grained, without imbedded larger crystals; others inclose in this groundmass large crystals of feldspar, alone or

associated with large grains of glassy quartz; still others have a completely crystalline, granite-like structure.

A small proportion of the pebbles consists of compact and of amygdaloidal diabases; the cavities of the amygdaloid pebbles are replenished with the usual variety of minerals, and it is distinctly observable that these minerals were already filling the cavities of the rock before its waterworn fragments became part of the conglomerate bed.

At Eagle River the width of this conglomerate belt is not visible, as it continues far out into the lake, but at Eagle Harbor it is found to be about a mile wide and on the north side succeeded again by diabasic rocks which project in a row of cliffs along the shore line and form the foundation of the lighthouse at the entrance to the harbor.

The above mentioned Ashbed, in the vicinity of Eagle River, a belt from 80 to 100 feet in width, consists of dark brown, earthy-looking rock masses, readily decomposing into small fragments on exposure, which are a brecciated mixture of fragmental amygdaloid masses partially worn and rounded, with a dark brown, fine-grained, interstitial cement-mass of dull fracture, which is evidently of sedimentary nature. Sometimes this sedimentary material prevails and the amygdaloidal rock is distantly imbedded in it; other times the amygdaloid forms the greater bulk, and narrow seams of the sedimentary rock mass unite them. At the North Cliff mine well laminated, dark brown, compact sandrock ledges are found interposed between the amygdaloidal portions of the belt.

The amygdaloidal rock varies in quality; most of it has the fine-grained structure of the so called Ashbed diabase and groups of porphyritically segregated feldspar crystals are scattered through it; the color is usually reddish brown, sometimes grayish; part of it is compact, hard, other portions are soft, porous. The amygdules consist of calcspar, laumonite, delessite and quartz; in some parts of the old Phœnix mine nearly all amygdules are filled with transparent, glassy datolite, which is rose-colored by intermingled fine scales of copper; some of the amygdules are almost entirely filled with copper, but the main mass of the metal occurs in hackly masses in interstitial fissure seams.

In the North Cliff mine, old Phœnix mine, Garden City mine

and Copper Falls mine, all of which are opened in the Ashbed, transverse fissure veins intersect this belt, which contribute a large share to the product of the mines.

Some of these veins resemble in rock character the fissure vein of the Cliff mine, being of quartzose and prehnitic nature; others are prevalently composed of calcspar, laumonite and datolite, which minerals form the cement of angular fragments of the wall rock which fell into the crevices, and constitute with them a breccia.

The amygdaloidal rock adjoining these brecciated veins is at the Copper Falls mine and the Garden City mine often much altered into a dark green rock mass, full of irregular cavities and crevices which are replenished with intensely red colored analcite crystals associated with prisms of natrolite and with calcspar. The green mother-rock consists to great extent of an amorphous, serpentine-like mass, mingled with radiated delessite concretions, which rock mass is by gradations linked together with the less altered amygdaloidal rock, and betrays its being an alteration product of the latter.

At the Copper Falls mine a tunnel 4,525 feet in length has been driven into the hillside horizontally across the strata dipping under an angle of 27 degrees to the north. Two thousand eight hundred feet of this length from the entrance of the tunnel are made up by an alternation of amygdaloidal and compact diabasic belts with five different belts of sandrock or respectively conglomerates; then comes the Ashbed which in its intersection is 150 feet wide; beyond this the tunnel is continued for the distance of 1,560 feet, intersecting an alternation of amygdaloidal and compact diabase belts. I omitted to give the measurements of all the intersected beds recorded in the journals of the mine as not of sufficient interest for the generality of the readers.

North of the adit of this tunnel the great conglomerate belt mentioned before in the Eagle River section, is near by exposed, and fills the entire interval from here to the lake shore, a mile in width. Outside, in the lake, a row of cliffs of diabasic rock projects, which are the same belt which at Eagle Harbor forms part of the mainland at the lighthouse point. This outer amygdaloidal diabase belt is intersected by copper-bearing veins from which, by superficial trenching, large masses of copper had been

extracted by miners many years ago; the openings are at present all filled with water.

The (new) Phœnix mine, located in front of the Greenstone bluffs, next to the gap through which Eagle River finds its outlet toward the lake, works in a similar fissure vein as the Cliff mine. The geological structure of the succession of beds intersected by the mine is about the same as in the Cliff mine; also here the Allouez conglomerate is merely indicated by the so called slide, while intermediate between the two mines, not much over a mile apart, a narrow conglomerate seam is found in this position, naturally exposed at the base of the vertical cliffs.

At the hundred-fathom level of the Phœnix mine another sedimentary seam occurs, which, in lower levels, widens to six and even ten feet, and then shows the nature of a conglomerate. This belt, supposed to be the equivalent of the Houghton conglomerate, has not been met with in the Cliff mine, but it is represented in the Central mine, four miles northeast of the Phœnix, which mine likewise follows a fissure vein and has its shafts at the base of the greenstone bluffs.

Between the two mines is another working mine, the St. Clair mine; it follows a fissure vein of the same lithological character as the other mentioned fissure veins.

At the Central mine, the Allouez conglomerate is well developed, in a thickness of 15 to 20 feet; it contains no appreciable quantity of copper there. The other conglomerate, believed to be the equivalent of the Houghton conglomerate, is struck in Shaft No. 2, at a distance of 665 feet below the Allouez conglomerate exposed at the base of the bluffs. The thickness of this belt is about eight feet; its cement, and partially also its pebbles, have been much altered and transformed into a porous, light yellowish green epidote mass, which is richly impregnated with copper, but the miners simply passed through it without drifting sideways into the ledge. Lower down, in the 160-fathom level of the same shaft, another conglomerate seam is struck, which is only three or four feet in thickness, but remarkably rich in copper. Here side-drifts are opened into it, which contribute a good share to the product of the mine. The vertical distance of this belt from the Allouez conglomerate is 1,100 feet; it is thought to be the analogon of the Calumet conglomerate.

The fissure rock of the Central mine has the same nature as that of the Cliff and Phœnix mines; it was very rich in its upper levels, but going down on it a general decrease in its productiveness was observed, and it was feared for a while it might grow poorer in the same rate by sinking deeper on it, but later work opening deeper levels disclosed again a wealth of the vein equal to that of the richest portions of it in the higher levels.

Much of the copper in the Central mine occurs in larger masses, some a good many tons in weight, which are surrounded by calcspar, prehnite, laumonite, and quartz, and have usually not their own crystalline form, but are adapted to the interstices left between the other minerals; sometimes, however, the copper formed in free cavities and then is found in most beautiful crystals associated with similarly perfect crystals of calcspar, apophyllite, analcite, natrolite, datolite, and quartz; likewise is silver a frequent associate of the copper.

These mineral specimens rarely come into the hands of the mining officials, and are an article of trade to which the laborers of the mine think themselves privileged. The number of travelers visiting the copper region, all desirous to gather some of these curiosities, have in the course of time caused the venders to raise their prices to fabulous height. Specimens of crystallized copper bring from five to twenty-five dollars and more, and an instance is known to me where a crystal of calcspar of the size of a hen's egg was, from the first hand, sold for eighty dollars, and the second purchaser paid ninety-five dollars for it.

East of the Central mine, along the base of the Greenstone range, a great number of old mining locations are met with which have been for a good while abandoned. All followed transverse fissure veins, and from some of them a considerable amount of copper was gained.

The next place where work is done is the Delaware mine, which formerly mined a fissure vein, but now, in the hands of new owners, is called the Conglomerate mine, as the Allouez conglomerate belt is the stratum which is mined for copper. Outcrops of this rock belt are noticeable all along the base of the bluffs from the Central mine to the Delaware mine. In some of these localities the belt is not over three or four feet wide; in others it has a thickness from 20 to 30 feet, which is the case

at the Delaware mine. The dip of the strata at the mine is 23 degrees to the north. The copper is very unequally distributed in this rock; large stretches of the belt are almost barren of the metal, then again patches are met with which are very rich; a good portion of the mined rock has therefore to be rejected. The average yield of the rock sent to the stamps is not over one and one-fifth per cent, but it is expected to make even this low percentage profitable by operating on a large scale. For this purpose the company erected a new stamp mill at Lac La Belle, and connected it with the mine by a railroad seven miles long. The mill has three large Ball stamps, of which two are in constant use; they are capable of stamping two hundred tons of rock daily.

The succession of rock beds underlying the conglomerate belt of the mine is to the extent of 400 or 500 feet of strata naturally exposed on the lower part of the hillslope. It is an alternation of amygdaloid belts, some of which are cupriferous, with compact diabasic belts. Farther south, most of the surface is covered with drift deposits, and the few rock projections seen at intervals are too far apart to learn by them much of the details in the succession, but we observe a conformity in strike and dip of the beds from the Delaware mine down to Lac La Belle, can therefore, with propriety, suggest that in going to the lake we meet constantly with lower strata.

By explorations with the diamond drill the occurrence of the two conglomerate belts intersected by the shafts of the Central mine has also at the Delaware mine been ascertained. The first, thought to be the Houghton conglomerate, is found not far from the old stamp mills in the sole of the valley. The second, identified with the Calumet conglomerate, has been struck 400 feet beneath the surface, southeast of the location, not far from the bridge across Montreal River. A third belt of conglomerate, 150 feet wide, is intersected by a railroad-cut two miles south of the former place, near the center of Sec. 30, T. 58, R. 29. A large proportion of the pebbles of this belt is amygdaloidal and compact diabase; the balance is made up by porphyry pebbles; the cementing interstitial seams are much impregnated with epidote, but no copper seems to occur in it. Not many steps off from this place conglomerate boulders are mingled with the drift masses, which are richly impregnated with copper in the form

of malachite. They seem not to belong to this belt and are probably transported from a northern belt.

South of this conglomerate belt unto the shore of Lac La Belle a great number of diabasic and amygdaloidal rock belts are found exposed along the railroad track and the wagon road, but several intersecting rock seams which I will describe below are not seen in these routes denuded.

Next to the conglomerate succeeds a fine-grained compact diabase of black color, which cleaves in even slabs an inch or two in thickness; the same rock is largely exposed on top of Bohemian Mountain at the Mendota location.

Farther south several amygdaloidal belts of purplish brown color with epidote, calcspar, and delessite amygdules occur; one of them is on the cleavage faces coated with malachite. These alternate with belts of compact diabase which contain numerous epidotic seams recementing the shattered rock masses.

The lowest rock belt in this large succession is a conglomerate 80 or 90 feet thick which projects in high bluffs short distance off from the lake shore. The stamp mills are built close to their front, whereby the advantage is gained of dumping the rock from the railroad cars into the building, a story above the Ball stamps.

This conglomerate is much darker colored than the conglomerates north of it; the cement consists of trappean debris and is locally impregnated with epidote; the pebbles are also in a great measure formed of diabase and amygdaloidal rock. The porphyry pebbles are nearly all of the fine-grained, homogeneous, jaspery kind, which rock occurs in a large belt interstratified with the diabasic rocks of the Bohemian Range at Mount Houghton, and from there extending six or eight miles farther to the east without interruption. Not only rounded pebbles of this porphyry enter into the composition of this conglomerate, but a great quantity of such rock is enclosed in sharp, angular fragments, sometimes even in large blocks. The rock belt is much decayed on the surface. An efflorescence of malachite on the rock faces is frequently noticeable, but it does not contain any larger quantity of copper.

Ascending from the lake shore to the Mendota mine on top of Bohemian Mountain, we see first, near the dwelling houses at the base of the mountain, the before mentioned conglomerate

exposed in the road bed. Above it an alternation of amygdaloidal seams with epidotic diabase belts succeeds, amounting to about 120 or 130 feet. Next higher follows a large belt of fine-grained, dark blackish, gray colored, glistening diabase, exhibiting the so called lustre-mottled structure. The plagioclase in its composition is turbid, rarely exhibiting polysynthetic striation; the augite is in part unaltered, transparent with pale brownish color; another part is green colored and of fibrous structure, indicating its transformation into hornblende; in addition to these, numerous olivine grains are disseminated, besides magnetite, which two latter minerals are always found closely associated.

In the farther ascent we find about midways of the mountain slope a very wide belt of coarsely crystalline rock, described by earlier writers under the name of syenite, and recently by Prof. Irving as orthoclase gabbro. It consists of about equal quantities of red feldspar, probably all orthoclase, and of uralitic hornblende crystals, which under the microscope very frequently enclose remnants of unaltered augite, of which they are a paramorphic product. Clusters of magnetite crystals or might-be titan-iron are copiously disseminated, besides translucid grains of quartz and epidote crystals; in some but not in all of the sections apatite prisms occur. The red color of the feldspar is not uniform, and is due to a seamy or cloudy infiltration of hematite pigment into the originally colorless mass. The rock above described as wall rock of a fissure vein at the old Phœnix mine is very similar to this rock. The red feldspar crystals in this latter are not all orthoclase, as some exhibit polysynthetic striation; a part of the augite in that rock is perfectly fresh and transparent and the altered crystals of it have not the perfect cleavage of the hornblende as in the rock of Lac La Belle; oftener the transformation appears to have resulted in the production of chlorite. Intimately associated with this rock belt are seams of a red colored crystalline rock which resembles the granitoid pebbles in the Calumet and other conglomerate belts. It consists of an aggregation of red orthoclase crystals with distantly interspersed altered crystals of augite changed into a whitish, soft, steatite-like mineral intermingled with chlorite scales. Between the interstices of the orthoclase crystals occurs a good proportion of transparent quartz grains of

very irregular shape; also magnetite granules are sparingly scattered.

This rock is merely a modification of the orthoclase gabbro, in which by local segregation the feldspathic constituent largely prevails over the augitic. Its seams are rarely sharply defined from the adjoining gabbro; they merge with each other by gradations.

This red rock must not be confounded with the red porphyry forming the summit of the neighboring Mount Houghton; there is no analogy between them.

A very good opportunity to see exposures of the gabbro and the associated red rock is offered by the lower adit of the Mendota mine and in the ravine above it. On the burrows in front of the adit a large amount of a dark green, coarsely crystalline rock is thrown out, which microscopically shows the distinct outlines of the former feldspar crystals and intermediate augite crystals originally composing it, but the entire mass is changed into a soft, steatite-like substance, which in thin sections under the microscope shows a minutely crystalline aggregate polarization; the former augite crystals appear more turbid and darker than the pseudomorph of the feldspar crystals, and the interstices between these are filled with quartz. Magnetite is disseminated in clusters as in the orthoclase gabbro, of which I suppose this rock is a pseudomorphous product.

In the same horizon occurs a belt of coarsely crystalline olivine gabbro, which in hand specimens is not distinguishable from the same rock found in the Penokee region or at Duluth. Its components are transparent crystals of plagioclase, pale brownish augite, and yellowish green olivine, besides some magnetite or titan-iron. Large, freshly quarried blocks of this rock were piled up on the roadside, together with blocks of the orthoclase gabbro, to be used as building material for the Lac La Belle stamp mills. I did not succeed to find this rock belt in the quarry, some distance above, on the hillside, but the rock unquestionably came from there. Above the orthoclase gabbro belt, which is not much less than 200 feet thick, succeeds an almost equally large belt of a gray, lustre-mottled diabase, projecting in vertical cliffs on the summit part of the hillslope. It is middling fine-grained; the augite is almost completely changed into hornblende. Considerable similarity exists between

this rock and the other diabase next below the orthoclase gabbro. Farther back on the plateau of the hill, a very fine-grained, compact, black colored diabase belt succeeds, which is the same as the before mentioned rock found exposed on the roadside at the base of the north slope of the hill. Next above it is an amygdaloid belt, and this is overlain by a conglomerate belt which is probably the same as the one intersected by the railroad track first met with, coming from the Delaware mine.

The just described succession of rock beds composing Bohemian Mountain, is transversely intersected by numerous fissure veins, filled with calcspar in association with chalcocite.

A number of years ago extensive preparations were made to mine these veins, but after a few years trial the work was abandoned, as the amount of copper ore obtained would not repay for the expense of mining it.

The lower division of the Keweenaw group composes the range of hills east of Bohemian Mountain, between the shore of Bête Grise Bay and the valley of Montreal River. The shore line is, with the exception of a few sand beaches, bordered with rock cliffs all the way out to the end point of the Peninsula, and offers, therefore, an excellent opportunity to examine this part of the group.

In several localities along the shore the discordant contact of the eastern sandstones with the Keweenaw rock series is observable.

One of such localities is situated near the quarter-post on the south line of Sec. 26, T. 58, R. 29, about a half a mile northeast of the outlet of Lac La Belle into Bête Grise bay. We see there a large succession of light colored, whitish and red blotched sandstones, alternating with several narrow seams of a dark colored, reddish brown breccia, consisting of small, little water-worn, fragments of diabasic and felsitic rocks like those largely exposed in the cliffs adjoining the shore. This group of sandrock and breccia beds dipping under an angle of about 35 degrees southward, is seen in immediate contact with a belt of lustre-mottled diabase which dips under a high angle to the north. The diabase belt is very much shattered and recemented by a network of calcspar and laumonite seams; it alternates with intermediate conglomeratic seams formed of rounded and of angular fragments of compact and of amygdaloidal diabase, and of an abundant cement of a dark reddish brown colored, fine-grained, sedimen-

tary material, which generally has a dull earthy fracture, but often also is quite compact and has a smooth, conchoidal, almost flinty fracture. It resembles in this latter case most strikingly the red felsites of which I will have subsequently to describe large exposures.

The line of contact between the sandrock and the diabasic rocks is seen in part above the water-level, but much of it submerged in shallow water, and is plainly visible for the distance of about a quarter of a mile eastward; the succession of sandrock ledges is observable far out into the lake; many of them exhibit ripple-marked surfaces. About a mile northeast of this locality is the summit of Mount Houghton, 847 feet high; its slope towards the lake is formed by various modifications of fine-grained diabase with interposed amygdaloidal seams; the top part consists of a red, fine-grained felsite belt, amounting to great thickness; the north slope of the mountain is formed again of a succession of diabasic rock belts. This felsitic rock exhibits very frequently a distinctly banded, laminated structure; it is hard, very brittle, and breaks under the stroke of the hammer into numerous sharp-edged, irregular fragments, so that only with difficulty hand specimens of a desired shape can be procured. A close relationship exists between this rock and the quartz porphyries which form the majority of the pebbles in the Calumet conglomerate, as far as the ground mass is concerned, but it rarely incloses porphyritically segregated, larger single feldspar crystals or quartz grains.

Thin sections of the felsite of Mount Houghton appear under the miscroscope as an aggregate of turbid feldspar crystals, with dimly defined prismatic outlines, in intermixture with very irregularly shaped, indented or ramose masses of transparent quartz, both minerals constituting a network of which one fills the meshes of the other. Very often we find also the longitudinal axis of the two minerals directed in conformity with the lamination in the banded portions of the rock. As an additional component have to be mentioned copiously disseminated black molecules which, in part at least, are magnetite or martite granules. Some of the darker grains show a degree of transparency with brownish green color, which might be augite.

In polarized light, under crossed nicols, we observe a network of dark seams inclosing luminous dots recognizable as feldspar

or patches of quartz; on revolution of the object the dark portions become, in some position, luminous, once this part and another time another; actually isotropic portions of the mass I could not observe or discover. Identical felsites with the Mount Houghton rock, composed the next high hill, one mile and a half east of the latter and a half mile south, very close to the shore; it occupies the north half of Sec. 29, T. 58, R. 28, presenting high vertical cliffs. The lower outlines of the belt, close to the water's edge, which most likely are loosened masses, slid down, repose on the lustre-mottled diabase rock, which, with local interruptions by the before mentioned brecciated or conglomeratic amygdaloidal rock seams formed the shore-cliffs from the place where the eastern sandstone is seen in contiguity with them, up to here. The felsite of these shore-cliffs has the structure of a breccia; its cementing seams are often infiltrated with malachite or with red oxide of copper.

Not quite a half mile east of the shore-cliffs of felsite, near the center of Sec. 29, another large patch of the eastern sandstone is seen in contact with the lustre-mottled diabase. The inclination of the sandrock beds in this place is not quite as steep as it was in the first described locality; still they have a distinct southern dip, steepest off shore, and diminishing toward the shore, near their contact line with the diabase, where the strata have an almost completely horizontal position, which circumstance makes me suggest as the possible cause of the inclined position of the strata an underwashing of the beds in the lake-bottom and the subsequent breaking down of the more superficial strata. Their discordance with the diabasic rock belt is here just as plainly observable as in the former place; crevices in the diabase are often found replenished with sandrock.

Leaving this place, we find eastward to the mouth of Montreal River, constant exposures of conglomeratic and brecciated rock masses formed of diabasic and amygdaloidal fragments, cemented by an abundant sedimentary interstitial mass, which entered the superficial cavities of the amygdaloidal rock, in proof that they were not already replenished with other minerals at the time the fragments became embedded in the conglomerate.

At times the conglomerate rock recedes from the shore and the underlying lustre-mottled diabase forms the borders of the lake; its presence is recognizable from a distance by the conspicuity

of the network of spar and laumonite seams intersecting it in all the exposures on the whole length of the shore.

The cementing seams of the amygdaloid conglomerates consist usually of a fine-grained, dark purplish brown colored, not very hard mass, with a dull earthy fracture, but locally it is found to be very hard and compact, with a smooth, almost flinty fracture, in which condition its resemblance to the before mentioned felsitic rock masses is so great as to make it difficult to distinguish one from the other.

Montreal River runs over a stairlike succession of cliffs into the lake, which cliffs consist of the often before mentioned lustre-mottled diabase, whose thickness here is seen to be quite large; the strata dip under a high angle northward, like all the remainder of succeeding rock beds. North of this belt follows a repeated alternation of amygdaloidal seams, with others of compact diabase. At the first great bend of the river a little more than a quarter of a mile from the shore is an amygdaloidal conglomerate belt exposed in the bed of the stream; interstratified and alternating with these layers are several seams of compact diabase from six to eight feet wide. Farther north, compact diabase rocks are incumbent, which amount to greater thickness. Next above follows a wide belt of a very fine-grained, dark purplish brown colored, hard but very brittle rock, which, under the microscope, shows the structure of the so called Ashbed diabase; its irregular splintery cleavage makes it somewhat resemble very dark colored specimens of a felsitic rock. It forms the foot-wall of a large belt of felsite in brecciated condition, and above this breccia follows a still larger belt of a coarse conglomerate, formed of rounded and angular felsite pebbles, besides a good proportion of amygdaloidal and diabasic pebbles.

The brecciated rock consists of small, angular fragments of brick-red felsite, firmly cemented together by interstitial seams of somewhat different shade of color, but of almost the same quality as the enclosed pebbles. Within these seams are numerous well formed feldspar crystals seggregated, and with them small morsels of diabase are found plentifully disseminated. The position of this breccia belt is in the line of strike with large felsite outcrops on the east and west sides; its relation to the incumbent conglomerate, which essentially is composed of the same rock material, I was not able to ascertain, as the interval

between the exposures of the two belts is covered with drift masses.

North of the conglomerate belt the trail along the river up to the Girard mine leads across several disconnected outcrops of diabasic and amygdaloidal rock belts, but for long stretches the surface is covered with drift masses; therefore not much could be learned of the succession of strata in this part. Proceeding along the shore east of the mouth of Montreal River, the shore is found lined with high bluffs of the lustre-mottled diabase, intersected with reticulated seams of calcspar and laumonite, which rock masses locally change into a conglomerate mass, composed of diabase and amygdaloid fragments, rounded and angular; often also a good proportion of epidotic rock masses are mingled in. The cementing mass as before described is a dark brown, fine-grained, sedimentary mud mass, which in cloudy blotches has the nature of a pale green epidote rock, clearly being the result of a secondary paramorphosis.

In the small bay used as a fishing station, on the south line of Sec. 26, T. 58, R. 28, a large isolated outcrop of felsitic rock masses projects in high cliffs at the shore; a quarter of a mile east of it we find the promontory forming the opposite side of the bay, totally composed of felsites which here protrude in a belt at least 500 feet in thickness. The rock mass is the same as that of the summit of Mount Houghton and of the large hill in the north half of Sec. 29. Locally the rock has a brecciated structure, but the great bulk of the belt is a homogeneous solid mass, full of cleavage cracks; its color is brick-red or purplish brown; a laminated, seamy structure of the rock bed is sometimes observable, but not in a degree as the rock of Mount Houghton and other more eastern outcrops exhibit it. On the north side of this belt a belt of porphyritic diabase is seen to overlie it, which consists of a minutely crystalline diabasic groundmass, enclosing numerous delessite amygdules, besides a large amount of red feldspar crystals, many of the size a half an inch in length. This is the only locality on Keweenaw Peninsula where this kind of a diabase occurred to me, while in the Gogebic Range this variety of diabase is very common. Of the same rock disseminated with very large feldspar crystals, in clusters, consists also the greatest part of the diabase pebbles inclosed within the large conglomerate

belt on Siskowit Bay at Isle Royale. The promontorial point on the line between Secs. 35 and 36 consists of the same porphyritic diabase which forms the hanging of the felsite belts from here further east, to the old location of the New England mine in Sec. 30, T. 58, R. 27; we find four different belts of felsitic rock, interstratified with diabase belts and amygdaloidal conglomerate seams. The first felsitic belt is found near the center of the south line of the S. W. ¼ of Sec. 25; it has a brecciated structure and differs from the ordinary felsite by a peculiar state of decomposition, being porous, gritty, resembling a sandrock; otherwise it perfectly corresponds with the brecciated felsite masses of which several other belts occur some distance further east. The thickness of this belt is only about five feet, and it dips under a high angle north.

On the east side of this narrow belt of brecciated felsite follow compact beds of diabase in alternation with seams of the often before encountered amygdaloid conglomerate. Near the east line of T. 58, R. 28, occurs another belt of brecciated felsite, then again, compact diabase beds and amygdaloid conglomerate east of it.

In Sec. 30 of the adjoining town, R. 27, the shore is almost through the entire width of the section bordered with outcrops of a very large felsite belt which trends parallel with it, dipping under an angle of about 70 degrees to the north.

The felsite has in this locality a remarkably well laminated, banded structure by regular alternation of differently colored, narrow, almost linear seams, which banded structure is particularly obvious on weathered surfaces. A succession of such regularly laminated beds, amounting to near a hundred feet, is exposed on a peninsular spur of cliffs projecting into the lake, and traceable far out beneath the water-level.

The incumbent higher beds of the felsite belt, cropping out on the beach, differ some from the very compact strata. Certain layers have a concretionary, spherulitic structure, which deceivingly resembles the concretionary structure not rarely seen in sedimentary rock beds. These concretionary beds exhibit like the others a laminated structure; the superimposed laminae connect among themselves vertically by transverse bars likewise consisting of aggregated, warty globules of different size; some of them exhibit a fibrous radiation from the center. The

intermediate space between these layers of very compact consistency are filled with a lighter colored, somewhat porous silico-feldspathic mass in progress of decomposition to kaolinite.

Another variety of the rock is composed of a reticulated intermixture of such concretionary nodules with a softer, dull, earthy-looking, red substance, which incloses large, whitish colored, much shattered feldspar crystals, the clefts of which are infiltrated with the red material.

Still another form of the rock is full of irregular, lobate, amygdaloidal cavities, lined with a coating of quartz crystals or of chalcedony, or completely filled with them. Often are leaflets of metallic copper inclosed by the quartz. Some other cavities are replenished with prehnite and other zeolitic minerals. Thin sections of this amygdaloidal felsite microscopically examined show the groundmass surrounding the amygdaloidal spaces to be formed of intimately reunited fragmental portions of felsite substance, some of which are homogeneous, compact, others seamy and cellulose. Amygdaloidal felsite masses occur also on the submerged reef of Stannard Rock lighthouse and in the Porcupine Mountains in the bed of the headwaters of Carp River.

The uppermost layers of this felsite belt are a coarse breccia of partly angular, partly rounded, water-worn felsite fragments with a light colored, porous cement, greenish colored by impregnation with malachite, which most likely is a secondary product of a small amount of metallic copper and of its red oxide, both of which are recognizable in the cement. This breccia is altogether different from the compact, brecciated felsite masses, previously described as occurring near the east line of T. 58, R. 28, and a mile north of the mouth of Montreal River. The cementing substance of these has the wavy, tortuous, fluidal structure, bending round the enclosed fragment, which is well represented on Plate 13, Figs. 9 to 12, in Mr. Irving's work on Lake Superior rocks.

The brecciated form of these rock belts first induced me to suppose their aqueous origin, as it is hard to imagine the injection of a fire-fluid mass into the accumulated mass of small fragments, some of which are diabase fragments, without causing a fusion of them, at least partially, but as the cement differs little from the material of the felsite fragments and

incloses sharply defined feldspar crystals like they do, we must also admit that both formed in the same way.

The felsites of the Bohemian Range show in many other respects qualities as well compatible with a rock formed by aqueous interference as with an eruptive rock, but as the felsites are so closely allied with the quartz-porphyries composing the south belt in the Porcupine Mountains, and also represented in an exposure on the railroad above the Calumet stamps which bear indisputable marks of their eruptive origin, we cannot otherwise than presume the same origin for the felsites.

The occurrence of isotropic glassy portions observed by some microscopists in thin sections of felsite, which would be a positive proof of their eruptive nature, I did never observe with positiveness. A large proportion of the rock mass becomes dark under crossed nicols, but as far as in such minutely granular aggregate can be observed, every one of the dark molecules transmits light on revolution of the stage in a certain position; small, interstitial seams of glass substance might be overlooked, but as a rule these felsites are totally formed of individualized crystalline material.

The beds incumbent on the last described felsite belt are alternating, compact and amygdaloidal diabase belts, which present themselves in their succession by following the shore farther to the east, toward Union Bay. One of the diabase belts is crowded with globular concretions of radiated thomsonite masses, rose-colored by intermixture of delicate leaflets of metallic copper.

A great many fissure veins intersecting the diabase are observable on the shore; they consist principally of calcspar, laumonite and quartz; some of them are filled with prehnite charged with copper, which induced, years ago, some mining companies to establish locations on the shore, but, as the burrows show, mining was not continued long; the veins were found too poor in copper to encourage the continuation of the exploratory work. From Union Bay to the extreme end of Keweenaw Peninsula, I did not examine the shore outcrops. Seen from a distance, the northeast part of the bay appeared to be lined with arenaceous sedimentary rock beds.

Striking here from the shore northward, the densely timbered condition of the country offers no opportunity to see connected

exposures of the rock beds until we approach the Greenstone Range, on which numerous abandoned mines are met with. We find the Keweenaw mine in the S. E. ¼ of Sec. 13, T. 58, R. 28, on the south slope of the Greenstone Range. Different amygdaloidal belts are uncovered here by the miner, and at the base of the cliffs the equivalent of the Allouez conglomerate crops out. The bluffs are formed of the coarsely crystalline diabase, which fully resembles the diabase composing the top of the bluffs at the Cliff mine.

On the north side of the range, the Vulcan, New York, and Michigan mines are situated.

Going west, we find the Philadelphia and Boston mines on the south slope of the range, and farther west the Star mine. Opposite the latter, on the north slope, is the Clark mine. On the south slope of the Greenstone Range a great number of different diabase and amygdaloid beds follow each other in alternate succession, all of which can be seen well exposed on the road leading from the Girard mine to the Star mine. At the crossing of Montreal River, a wide belt of diabase causes falls in the river about 30 feet high; overlying is a belt of amygdaloid, then succeeds a very dark colored diabase, and so on. Six or seven different amygdaloid belts, with intermediate diabase belts, present themselves before we reach the base of the Greenstone bluffs, at which the cupriferous Allouez conglomerate belt is seen in a thickness of about 35 feet; some mining has been done in it, but it was not a success. Several of the amygdaloid belts have been also mined at the Star location. One very hard, purplish gray amygdaloid, with prehnite and datolite amygdules, is quite rich in copper, but at present no work is done in it. Several transverse fissure veins, principally filled with calcspar and laumonite, had been followed on the Star location, but they were, with the exception of some local accumulations, poor in copper; likewise did I notice a prehnitic fissure vein opened on the location, which seemed to be more productive, but at present the places are altogether abandoned.

West of the Star mine are three or four other abandoned mining locations, on the south slope, which did some work in the Allouez conglomerate belt and in an underlying amygdaloid, besides mining fissure veins. Crossing the range at the Star mine, we find at the foot of the north slope the south shafts of

the Clark mine, which followed a prehnitic fissure vein intersecting the very coarsely crystalline diabase characteristic for the upper strata of the Greenstone Range.

The feldspar in a great portion of the wall rock of the vein is red colored, the augite is bright, translucid, with yellowish brown color, and the large proportion of olivine in the rocks is almost completely changed into a dull green, serpentine-like mass and partially into radiated clusters of chlorite or delessite. Pseudo-amygdaloidal spaces in this rock are sometimes filled with prehnite which incloses scales of copper.

About 500 steps north of the shafts at the Clark mine, right by the dwelling houses of the location, a wide brecciated amygdaloid belt, with brown, gritty cement crops out; it resembles the Ashbed of Eagle River. It is traceable quite a distance east and westward and can also, at the Aetna mine dwellings, be seen well denuded, holding a similar distance north of the Greenstone.

North of this belt occurs, on the west side of the Clark mine, close to the road, a large belt of ripple-marked, brown sandstone, overlain on the north side by another amygdaloid belt. The sandstone has been quarried for building purposes at the mine.

Three-fourths of a mile north of the Clark mine dwellings, another fissure vein has been mined, known by the name of East vein. It intersects a large belt of fine-grained, black diabase, an overlying amygdaloid belt, and then the large conglomerate belt continued up to here from Eagle River.

An adit is driven horizontally across the diabase, within which the vein was not very rich; in the amygdaloid belt the vein became very productive in small masses, so called barrel-copper. The vein rock there, consisting of prehnite, calcspar, quartz, contains a great many druse cavities, lined with fine crystals of calcspar, prehnite, analcite, feldspar, epidote, quartz, and particularly datolite in brilliant, transparent form, often aventurine-like, glistening from intermixture with most delicate leaflets of metallic copper. The copper in the vein occurs frequently in solid, large crystals, but the angles between the crystal facets are obtusely rounded, never sharp. Entering the conglomerate belt, the vein loses its prehnitic character and becomes very poor in copper; it is there mainly composed of calcspar and laumonite. The drift into the conglomerate has only been driven for about 40 feet, and then abandoned. On the strip of land intervening

between the dwellings and the adit of the east vein, considerable exploring work has been done in amygdaloid belts, of which several present themselves in alternation with compact diabasic rock masses, but although copper was found in all of these pits, the amount was too small to be profitably mined.

In this vicinity a belt of manganese ore occurs at the base of the before mentioned large conglomerate belt, and below an amygdaloid next succumbent beneath the conglomerate. The ore seam is from two to four feet wide, associated with calcspar; its foot-wall is a compact diabase; dip of the strata 50 degrees to the north. A small percentage of copper in the ore makes it unfit for some purposes, and the copious intermixture of calcspar is likewise depreciating its value; the mining of the ore has therefore been suspended since a good while. North of the large conglomerate belt, which extends to the shore of Copper Harbor, a belt of diabase full of agate nodules and delessite nodules projects in reefs in the harbor, and north of it, on the shore of the open lake, succeeds another conglomerate and sandrock belt, dipping northward in conformity with the other strata. A good many spar veins are seen to intersect these three last mentioned rock belts in the harbor, and in the bluffs at the shore. On the location of Fort Wilkins, in former years, a vein of black oxide of copper was mined, but at present all the pits are filled with drift sand, which covers the surface there to a depth of twenty and thirty feet.

On returning by the wagon road from Copper Harbor to the Delaware mine, my first starting point, I did not observe any particular geological features exhibited by natural outcrops or by the numerous abandoned mining places encountered on both sides of the Greenstone Range, which had not been seen before on the more eastern part of it, and not been already described. Nearly all of these mines were opened in transverse fissure veins.

The eastern continuation of the cupriferous conglomerate of the Delaware mine or the so called Allouez conglomerate shows itself in natural outcrops in many places on the side of the road, after it had crossed over to the south side of the range near the outlet of Mosquito Lake, which touches with its south end the north side of the Greenstone Range, and is bordered on the opposite, northern, end by a range of very conspicuous hills formed of the great conglomerate belt continued from Copper

Harbor almost without any interruption to Eagle River and farther south, retaining a width of almost a mile. This same belt is found in great width yet at the stamp mills of the Allouez mine, but farther south towards Portage Lake it is not exposed on account of deep drift deposits covering this part of the peninsula, and from the position of another belt of sandrock beds supposed to be identical with the rocks of the Nonesuch mine of the Ontonagon district and therefore positively younger than the great conglomerate, we must suppose that in the vicinity of Houghton this belt, immensely large, has shrunk to a thickness of scarcely a few hundred feet, if it is represented at all.

(5) ONTONAGON DISTRICT.

The general character of the Keweenaw rock series is found in the Ontonagon district, and in the region of Gogebic Lake, to be about the same as on Keweenaw Peninsula, but it would be an unsatisfactory labor to make an attempt of an indentification of the subordinate strata of the series with those of the Portage Lake country, as in remote localities a correspondence of the single beds in a succession never can be expected.

Examining the succession of rock beds from the shore of Ontonagon, backwards to the Minnesota mine, a distance of about twelve miles, we find on the shore, three miles east of Ontonagon village, cliffs of red colored or white and red mottled sandstones which are nearly horizontal; they correspond in quality with the sandrock beds exposed farther east, near the entrance into Portage Lake Canal and on a great portion of the intermediate part of the shore. Entirely similar sandrocks with a dip not exceeding 10 or 15 degrees northward are found exposed west of Ontonagon in the different creek beds this side of Iron River; their dip is not due north, but somewhat inclined eastward. Back from the shore the surface is covered with deep drift deposits of a stiff red clay and only rarely a deep ravine gives a chance to see a few ledges of sandrock on its bottom. The deepest cut made by the Ontonagon River has only in a few places denuded these beds, so that we have very imperfect knowledge of the succession of strata for an interval of eight miles south of Ontonagon.

About two miles north of Rockland we find in the head

branches of the Flint Steel River the first rock exposures which consist of a very large succession of grayish colored, somewhat micaceous, fine-grained sandstones, cleaving into thin, even flags with interstratified, more argillitic slate beds. In the lower part of the series several beds of coarse conglomerate of brownish color are found interposed. Still lower a large conglomerate belt succeeds which is not less than 600 or 800 feet wide; the cuts of the lately built railroad from Rockland to Ontonagon have fairly exposed this belt; its strata dip under an angle of 45 degrees to the north.

The gray colored, flaggy sandstones with argillitic seams are considered to be the equivalent of the strata of the Nonesuch mine 20 miles farther west; we see exposures of them all along in the intermediate space, and also eastward south of Maple Grove the same series of rock beds is found denuded in most all the ravines of the branches of Flint Steel River. South of the large conglomerate belt follow various amygdaloidal and compact diabase belts, then comes a large belt of quartz-porphyry which is well exposed in the N. W. ¼ of Sec. 9, T. 50, R. 39, next to the wagon road from Rockland to Ontonagon, about a mile north of the first mentioned village. On the railroad half a mile farther west this belt is not well exposed; only a few ledges of a compact, fine-grained, somewhat banded rock of dark purplish brown color seem to represent it there.

The porphyry of this belt varies in different shades of purplish brown; some portions are full of larger segregated crystals of feldspar and glassy grains of quartz; in others scarcely any quartz grains occur, while feldspar is abundant; still other portions inclose no larger crystals and are a homogeneous, fine-grained mass, with dull, conchoidal fracture. Under the microscope the groundmass is composed of a minutely granular mixture of turbid molecules which seem to be feldspar, and of a transparent, interstitial substance which is probably quartz; no really isotropic matter is between, but within this mass a large number of irregular, dark colored, impellucid granules are dispersed, which on the edges exhibit a slight permeability for the light; in addition, we find inclosed green dichroic hornblende prisms, most of them fractured or rounded on the edges, and the before mentioned larger feldspar crystals and quartz grains. A specimen of the homogeneous, fine-grained kind of

the rock, with no porphyritic segregation of feldspar crystals exhibits a truly fragmental structure, consisting of small, subangular fragments of turbid and iron-colored feldspar, of grains of quartz and of hornblende fragments cemented together. South of the porphyry belt an amygdaloid belt is exposed on the railroad, which consists of a brecciated intermixture of irregular, fragmental, amygdaloid masses cemented by abundant sedimentary interstitial seams of drab color, gritty and somewhat porous, absorbent; it has some resemblance with the Ashbed of Eagle River. Farther south a large belt of dark colored, compact diabase follows; part of it is very fine-grained like the Ashbed diabase, another part has the coarser grain of the ordinary diabases and carries olivine.

The interval from this belt to the hills of the National and Minnesota mines, about a mile in width, is filled with an alternating succession of compact diabase belts, amygdaloid and conglomerate or sandstone seams, of which conglomeratic seams six are known to occur, some of which are 50 feet wide, others only 12 or 15 feet.

The amygdaloids carry some copper in their exposures in the numerous ravines running down to the Ontonagon River, but only one of the belts next above the hanging wall of the National mine has been found rich enough to be profitably mined. The miners call this belt the north vein of the National mine. It is purplish brown colored, quite hard, sometimes even flinty in its fracture, its amygdules are filled with calcspar, prehnite, epidote, quartz, associated with copper, but the largest portion of copper in bulkier masses occurs in epidotic portions of the rock belt which intersect it in all directions. The underlying diabase belt, about 120 feet in thickness, is dark colored, middling fine-grained, or also coarser-grained, olivine-bearing, which latter mineral is partially changed into a purplish, iron-colored, micaceous mineral like rubellan. Numerous irregular, pseudo-amygdaloidal spaces in the rock masses are filled with the often before mentioned green aphanitic mineral resembling serpentine.

Beneath this belt and an underlying coarse conglomerate belt, a seam sometimes only a few inches wide, other times expanding to the width of three feet, and locally into much larger pocket-like dilatations, is composed of fragmental diabase masses, often

covered with a smooth, slickenside coating, wedged in between a seamy compound of dark green serpentines and fibrous chrysotile-like mineral in intermixture with calcspar, prehnite, laumonite and epidote and red feldspar, besides quartz, in which seam, called the south vein of the mine, the copper is intermingled in ramified, hackly, laminate masses, and often in larger ponderous concretions, many tons in weight; the largest of these found in the Minnesota mine weighed 500 tons.

In the National and Minnesota mines transverse fissure veins were met with, during the progress of the work, which at the crossing with the other copper-bearing belts were found very rich in copper and have been followed by drifts.

The conglomerate belt underlying the south vein of the National mine is about 20 or 30 feet thick; its lower portion is a fine-grained, brown sandrock. The copper masses of the above mentioned larger size often are partially imbedded within this conglomerate, as most of the metal has accumulated on the foot-wall side of the vein, and its pocket-like expansions intrude the underlying rock belt. Many of the blocks of conglomerate found in the burrows contain a considerable amount of malachite and red oxide of copper within the interstitial seams of the cement. Beneath the conglomerate belt an amygdaloid belt follows next; farther south a succession of compact and amygdaloidal diabase beds, amounting to over a mile in thickness, follows, which composes a second range of hills south of the hills of the National and Minnesota mines. The south slope of this second range sinks down to a drift plateau which borders the channel of Ontonagan River, and no more of the copper-bearing rocks is visible at the surface. All the rock ledges seen in the valley, if an erosion has laid them bare, are horizontal Silurian sandstone ledges. This belt of Keweenawan rocks beneath the Minnesota mine has, to some extent, been explored with the diamond drill by this company, but a much better knowledge of it we obtain by a great number of mines opened in this series east of the Minnesota mine.

We learn by them that five copper-bearing, amygdaloid belts, or in the miners' language, veins, occur south of the Minnesota belt, which all have received names from the places where such a belt has been principally mined. The first belt south of the Minnesota mine is the so called Knowlton vein, worked by the

Knowlton mine and by the adjoining Mass mine. I could not ascertain the exact distance between the two belts, but guessing at it from the distance of the old shafts opened in the Minnesota vein, north of the Mass mine, it must be about 2,500 feet. The distance of the other veins south of this has been accurately measured in a tunnel of the Mass mine driven across the range enclosing all of them; the length of the tunnel is 1,400 feet. One hundred and twenty feet south of the Knowlton vein occurs the Mass vein; 290 feet further the Champion vein is intersected; ninety feet further is the Ogema vein, and 260 feet south of it is the Evergreen vein. All these copper-bearing belts are parallel with the stratification of the range, not sharply defined from the surrounding rock masses by a demarkating line like a fissure vein is from its walls, and also the copper is not confined to the space practically considered as the vein, but occurs often in the adjoining rock masses less copiously. The vein-rock of the Mass mine is a rather hard, dark brown amygdaloid, interwoven with seams of calcspar, epidote, quartz, prehnite, and red feldspar. The copper is partly inclosed within the amygdules, but more of it occurs in heavier masses surrounded by calcspar, epidote and quartz, in seams intersecting the amygdaloid. Not rarely also porcelain-like datolite masses inclose the copper in well formed, perfect crystals. The Mass mine, like the adjoining Ridge mine and Adventure mine, is renowned for the occurrence of fine specimens of silver associated with copper. The Ridge mine, formerly the most important on the range, is at present almost abandoned. Its first shafts were opened in the Champion belt; later the Evergreen belt was principally mined on the location. The vein-rock of the Ridge mine is partly an epidotic mass, partly is composed of calcspar, quartz and red feldspar, which form a network of seams intersecting a hard amygdaloid; the interstices between the agglomerated spar and quartz crystals are often filled with snow-white, porcelain-like datolite; also the copper fills the interstitial spaces between these minerals, often in heavy masses.

The Adventure mine, next east of the Ridge mine, is for a good while abandoned; the work done there is scattered over different places, indicating that the copper was found in limited, pocket-like accumulations. The vein-rock in some of the openings is full of druse cavities, lined with fine crystals of calcspar, quartz, epidote, and red feldspar, in rhombical, salmon-colored

crystals, which look more like stilbite than feldspar, but their hard fusibility and resistance to the action of acids readily distinguishes them from this mineral.

East of the Adventure mine, on the same range, the old Bohemian mine has lately been opened under the name of Belt mine, and a large stamp mill was built a mile from the mine in the valley of Fire Steel River.

The conspicuous bluffs on the location inclose the five copper-bearing belts intersected in the tunnel of the Mass mine. The shaft presently opened on the south side of the bluffs is sunk on the Champion vein, a purplish gray colored amygdaloid, of crystalline grain with amygdules of calcspar and epidote, and intersected by numerous epidotic seams, porous or compact, in intermixture with spar, quartz, prehnite, feldspar, etc.; the intermingled copper occurs mostly in coarse, hackly masses; less of it is interspersed in grains and leaflets. On the north side of the bluffs new shafts have been opened in the Knowlton vein, following the inclination of the seam, which dips under an angle of 35 degrees north.

The belt is not well defined from the diabase in the hanging and on the foot-wall; the mined portion of the seam, in which most of the copper is concentrated, is between three and four feet wide, but locally becomes much wider. The vein matter is an amygdaloidal, brown and green mottled, brecciated rock, with cementing seams of spar, quartz, epidote, and much of the aphanitic, soft, green, serpentine-like mineral. The copper is inclosed in heavier sheets and in delicate leaflets, coating over the slickensided surface of the innumerable capillary fissures dividing the rock mass into small segments, rapidly disintegrating on exposure.

The other copper-bearing belts in the bluff are at present not yet opened. The old Bohemian mine had done some little work in the most southern Evergreen belt and in the Ogema belt.

The rock sent to the stamps, inclusive of the coarse mass-copper picked out at the mine, yields from three to three and three-fourths per cent of copper. At the time of my visit, one Ball stamp, eighteen inches in diameter, was in operation, capable of pounding 200 tons of rock daily; a second similar stamp is being put up, and will soon be put in operation.

On the north side of the Belt location, at the distance of about

one half a mile, old shafts and large burrows show that in previous years much work had been done in the belt corresponding with that of the Minnesota mine. The continuation of the Copper Range east of the Belt mine, in direct connection with the Portage Lake range, I have not specially examined; a large number of abandoned mining locations are encountered on this part of the range, some of which are reported to me as at one time very promising. Also the part of the Copper Range west of Rockland, on to Lake Gogebic, is, on its south side, one continuous string of mining locations, all of which are presently abandoned. These western mines worked nearly all in fissure veins, while the eastern almost exclusively followed seams parallel to the bedding of the range. The Forest or Victoria mine, occupying a very conspicuous position on the top of a hill, on the west side of Ontonagon River, three miles west of Rockland, is not opened in a fissure vein, but follows a belt supposed to be the equivalent of the Evergreen belt; an epidotic, amygdaloid rock on the burrows, contains considerable amount of copper, and it is said that in the days the mine was worked some large masses of copper were taken out of it.

Short distance west of the shafts, on the location, a conglomerate belt, underlying the amygdaloid of the mine, crops out on the roadside. The dip of the strata at the mine is under an angle of from 60 to 70 degrees northwestward.

South of the location, towards the west branch of the Ontonagon River, a succession of alternating, compact diabase belts and amygdaloid beds, amounting to over 1,200 feet, is well exposed; the lowest beds of the series project in high vertical bluffs along the narrow river valley, the base of which is surrounded by a terrace of drift deposits or by talus of the decomposing cliffs. The river bed is carved into a large succession of horizontal Silurian sandrock beds, over which the water flows in stairlike, small cascades, which, as is visible in time of low water, have excavated in the beds a great number of large and small round pot holes. The drift masses and the talus prevent the exposure of the discordant contact of the sandstones with the trappean rocks, but the intervening covered space is often so narrow that it would require not a great amount of digging to lay it open. West of the Victoria mine, I mention, among the great number of others, the Windsor, Trap, and Norwich mines,

joining together, which mined epidotic fissure veins, intersecting the very high bluffs of trappean rocks facing the valley of the west branch of Ontonagon River. At the base of these bluffs, a soft, crumby amygdaloid crops out, and beneath it a conglomerate belt, the thickness of which I could not see, as the lower part of the bed disappears under drift deposits which cover the bottom of the valley in which, in certain places, the horizontal Silurian sandstones have become denuded by erosions of the river.

Farther west on all the numerous mining locations formerly established there thick underbrush has grown up, so that no chance is left to gather much information by running over the places. In one place, only a mile east of the outlet of Lake Gogebic, in T. 49, R. 42, Sec. 35, a peculiar rock seam of great width is seen interstratified between diabase belts of the ordinary kind composing the range. This is a fine-grained, compact rock, pale red and greenish yellow speckled. Macroscopically it consists of a turbid, granular, feldspathic mass, greenish colored by intermingled epidote, in which globular concretionary masses of rosy color with fibrous concentrically radiated structure are thickly embedded; also distinct crystals of quartz were seen inclosed. Under the microscope much more of interstitial quartz masses is discernible mingled with the groundmass; the presence of some carbonate shows itself by slight effervescence of the rock treated with acid; the red fibrous mineral is not attacked by acids, and fusible with difficulty on the edges. In all probability is the rock described by Foster & Whitney's report, page 71, the same. Their specimens were found in Sec. 33, T. 49, R. 43.

The general character of this rock belt is in close relationship to that of the quartz-bearing porphyry, of which a very large belt, locally over a mile in width, forms in this township north of the trap range a separate parallel row of high hills, presenting towards the valley of Cascade River, a tributary of the Ontonagon, high vertical escarpments. The trap range has here a width of about four miles; its north side slopes gently down toward the before mentioned valley. The strata dip under an angle of about 50 degrees to the northwest.

The porphyry belt composing the range on the north side of the valley of Cascade River apparently reposes conformably on the diabase belts forming the range on the south side. I traced

this porphyry belt without interruption of the exposures across the north half of T. 49, R. 42; Secs. 7 to 12 are almost exclusively underlain by this rock. In the adjoining eastern township the belt is continued, trending in a more northeastern direction than before when its course was almost due east and west. In the line of strike of this porphyry belt we find farther east in T. 50, R. 41, four miles north of the Norwich mine on the road to Ontonagon, a series of rock beds exposed which differ in character from the just described porphyritic belt, being of a sub-porous, gritty nature, with dull fracture, devoid of disseminated quartz grains and only sparingly inclosing small feldspar crystals.

Under the microscope this rock consists of a minutely granular mass of red colored turbid feldspar sparingly intermingled with lobate interstitial masses of quartz and crowded with dark colored, ferruginous granules, dustlike disseminated, and also aggregated into small clusters; likewise distant grains of augite are observable. Most likely also the previously described outcrop of typical quartz-porphyry, a mile north of Rockland, is occupying a similar horizon with these western porphyries. The porphyry bluffs in T. 49, R's 42 and 41, are composed of bulky rock masses showing no stratification, but being intersected by innumerable irregular cleavage cracks, making the hard rock very brittle. The color varies in different shades from gray to brick-red and to dark liver-brown.

The very fine crypto-crystalline groundmass with flinty fracture is thickly studded with large reddish or also whitish colored feldspar crystals, besides obtusely angular crystals of glassy quartz which appear black in reflected light. The quartz frequently incloses besides air bubbles and small microlites, also detached lumps of the surrounding groundmass, and is intruded by club-shaped prolongations of the same which are in connection yet with the main mass. The feldspar crystals are usually intersected by a network of linear seams infiltrated with rusty, ferruginous matter; not rarely also irregular, hackly masses of transparent quartz occupy the interior of the feldspar crystals, probably secondary depositions replacing the feldspathic substance. The groundmass itself appears under the microscope as a curdled, reticulated intermixture of turbid, reddish colored aggregations of feldspar granules with an interstitial network

of quartz; a fluidal structure indicated by darker colored, wavy lineation is often observable. Locally portions of this porphyry belt have a completely crystalline, granite-like structure consisting of an agglomeration of larger sized red feldspar crystals in intermixture with colorless, transparent, irregularly-shaped quartz masses, which frequently inclose delicate apatite prisms, and with dark, greenish black colored crystalline molecules, consisting of augite or paramorphic products of it in association with magnetite granules. This granite-like structure is peculiar to eruptive rocks; the eruptive nature of granitoid porphyry is further proved by the occurrence of analogous rock masses in dyke form cutting across the lower beds of the Keweenaw group, as we find them for instance in the vicinity of Duluth, Minnesota.

The inclosure of small isolated lumps of the porphyritic groundmass within the quartz crystals segregated in it and their intrusion by club-shaped prolongations of the surrounding felsitic mass is another argument for the igneous origin of the porphyry, as this fact is only reasonably explainable by assuming the formation of the quartz crystals within a molten mass of which accidentally portions became enclosed while the masses were liquid. The fluidal lines so often observed in the porphyries are a farther proof of their once molten condition. Considering the great resemblance of the felsitic rocks which form another northern belt in the Porcupine Mountains, with this southern belt, we cannot otherwise than suggest the igneous origin of that, although it exhibits not as clearly the marks of an eruptive rock. The felsites of the Bohemian Range on Keweenaw Point are perfectly identical with the felsites of this north belt of the Porcupine Mountains, whose identity with the southern quartz-porphyry belt is farther evinced by a direct connection of the two belts in a horseshoe curve as it is represented on the map of Prof. Irving's work.

The porphyry belt trending across the north part of T. 49, R. 42, is, on its north side, succeeded by diabase and amygdaloid belts; they dip under a steep angle northwest, like the porphyry. Good exposures of these rock beds are found in the ravines of an east branch of Iron River, next to the southeast corner of Sec. 12, T. 49, R. 43. The diabase is middling fine-grained, dark blackish colored; the amygdaloids have their cavities filled with calcspar,

laumonite, delessite, prehnite, and quartz; an impregnation with copper I did not observe.

A mile north of the mentioned place, near the quarter-post on the south line of Sec. 1, projects an isolated knob of diabase, which is the last rock exposure seen on the trail from there to the Nonesuch mine. The rock is very fine-grained, with dull, earthy fracture; its color is dark purplish brown; dip northwest.

In the bed of Iron River, at the crossing in Sec. 25, T. 50, R. 43, a large amount of angular slabs of the sandrock of the Nonesuch group is found, indicating the intersection of this belt by the river at no great distance up the stream. On Little Iron River at the Nonesuch location, this sandrock formation named after the mine, is cut through by the river in a deep ravine, in which about 400 feet of strata are denuded, dipping southeast under an angle of 30 degrees. This rock series continues westward along the valley of Little Iron River, retaining its southeastern dip. The high hills bordering the north side of the river are composed at the base of diabase and amygdaloid belts dipping northward; their top part is formed by felsitic rocks identical with the felsites of the Bohemian Range on Keweenaw Point. This felsite dipping north in conformity with the trappean beds forms an immensely large belt extending eight miles westward from the mine in a width of more than two miles. Thence the rock belt makes a curve towards the south, in which direction I have not yet examined it. The northern extension of the felsite belt can be most advantageously examined by following the north line of the township from the top of the hill at the Nonesuch mine westward, as it corresponds pretty near with the south margin of the crest of the mountain chain on which the strata are almost without an interruption exposed in vertical bluffs. The northern part of this felsitic rock belt is best examined in the main head branch of Carp River, which drains the north slope of this range of hills and has carved a deep ravine into this belt and the succeeding higher strata.

Ascending the hill northwest of the Nonesuch, we find this terminal part of the range entirely composed of stratified layers of diabase amounting to great thickness, which dip under a moderate angle northeast. The larger portion of this series of beds of diabase has a reddish brown color, as the abundantly intermingled magnetite granules have almost completely changed

into red oxide; all of the beds are fine-grained, some very compact, others sub-porous, which latter are lighter colored, often dotted with rounded specks of pink color, which give the rock the appearance of an amygdaloid, but have actually discolored only portions of the mass in the same mode as we see the red sandstones of the Sault Ste. Mary's Canal variegated by discolored round specks.

Under the microscope is found in all the examined specimens olivine quite freely disseminated, partially altered peripherally into a purplish colored substance. The augitic constituent of the rock is likewise altered and has partially lost its clear transparency. A porphyritic segregation of larger feldspar crystals in the fine-grained groundmass of the diabase is frequently observed.

The felsitic rocks which are incumbent on this diabase belt are first met with a mile west of this promontorial point in the north part of Sec. 3, and thence uninterruptedly through Secs. 4, 5, and 6 of T. 50, R. 43. As before stated, the rock is the same brittle, compact, reddish colored, silico-feldspathic mass which composes the felsite belts of the Bohemian Range on Keweenaw Peninsula; portions of the belt have the structure of a breccia; a banded laminated structure is rarely observable in these eastern outcrops.

Thin sections of the rock appear under the microscope as a uniform microcrystalline curdled intermixture of reddish colored, somewhat turbid feldspar with interstitial quartz masses. Nearly always, dark impellucid ferruginous molecules of irregular form are found more or less copiously disseminated. In some portions of the rock, irregular dots composed exclusively of quartz grains clustered together, interrupt the homogeneity of the crystalline magma. The quartz usually incloses many microlites and air bubbles with a libelle,* capillary fissures of the quartz are sometimes infiltrated with purplish color, and here and there transparent grains clustered together are found scattered, which seem to be augite. No isotropic parts are observable except basal sections of quartz. In Sec. 4, at the base of the felsite bluffs, a fine-grained blackish colored compact diabase crops out in association with a coarse conglomeratic or brecciated mass of

[* Dr. Rominger means that the quartz, beside inclosing air-spaces, also incloses liquid in which there is a "libelle," i. e., a bubble of air or gas. L. L. H.]

amygdaloid blocks cemented by abundant sedimentary material of purplish brown color with dull earthy fracture, exactly like the amygdaloid breccias so frequently seen on the shore of Bête Grise Bay. Also further west in many places diabasic rocks can be seen exposed beneath the bluffs of felsite, as for instance on the north line of Sec. 7, in the fork between two creeks, where a porphyritic diabase occurs with copiously interspersed large red feldspar crystals in the minutely crystalline blackish groundmass. This rock is very similar to the porphyritic diabase which forms the hanging of the felsite of Bête Grise Bay on the north line of Sec. 35, T. 58, R. 28.

Near the west line of T. 50, R. 43, at the southwest corner of Sec. 7, the sandrock strata of the Nonesuch group, dipping under a steep angle southeastward, are largely exposed in the branches of a creek and by an exploratory shaft sunk there in search of the copper-bearing seam, which was discovered here equally rich in copper as at the Nonesuch mine.

Ascending higher on the hillslope we find the felsite next succumbent to the sandrock formation, but the massive condition of the felsite does not allow one to determine the nature of the contact, whether it is discordant or conformable, but on top of the range and further north the dip of the felsite is clearly seen to be in a northern direction. High knobs of felsite occur on the line between Secs. 1 and 2, of T. 50, R. 44, and on the south line of Sec. 2. The rock is here reddish brown colored, very compact, of flinty fracture, but locally a contorted well laminated structure is observed. South, on the line between 11 and 12, the rock has a purplish gray, almost whitish color, is gritty, rather porous, and encloses a great number of disseminated small crystals of iron oxide of black color with great lustre; this rock contains also numerous small druse cavities filled with quartz crystals; rarely also violet colored little cubes of fluorspar are enclosed.

The northwest corner of Sec. 11, T. 50, R. 44, is on top of a high knob of compact red felsite. Crossing the valley of Little Carp River on the line between Secs. 10 and 3, we find an opposite high knob composed of very coarse crystalline olivinitic diabase resembling the coarsest varieties of greenstone from the height of the bluffs at the Cliff mine.

A fine view of Lake Superior opens on the summit of this

hill. West of it no more felsite exposures are observable; the felsite belt bends here southward, following the valley of Little Carp River in which direction I did not follow it. The north side of the described felsite belt and a series of incumbent strata are well exposed in the main head branch of Carp River in Sec. 30, T. 51, R. 43.

Ascending from the Carp River road the ravine-like bed of the creek we see first a large conglomerate belt exposed dipping north; the lower strata of this belt are a compact fine-grained dark brown colored sandrock. Beneath it follows a belt of diabase about 200 feet wide; part of the belt is in compact layers; the greater portion has an amygdaloidal structure with prevailingly epidotic amygdules; certain amygdaloidal seams are brecciated, recemented by a fine-grained compact sedimentary mass. The next lower stratum is another conglomerate or rather breccia belt, consisting of the same material as the former, but the fragments are angular, very firmly cemented.

Then comes another series of diabase rock beds, the upper ones gray colored, the lower ones of reddish brown color, fine-grained with dull earthy fracture; some amygdaloidal seams, likewise of red color are found interstratified between the compact beds, the amygdules filled with epidote and quartz. Below this quite large series of red colored diabase beds follows the felsite in compact flinty brick-red colored, tolerably well laminated beds which are with difficulty distinguished from the overlying red diabase; on microscopical examination, however, the difference between the two rocks is quite obvious.

The felsite beds give occasion for a cascade about 25 feet high, above which constant exposures of the same rocks are seen in the creek bed for half a mile further on, as far as I went. Returning to the road and descending to Carp Lake, I found on the north side of the first mentioned conglomerate belt layers of compact diabase and interstratified amygdaloid seams, all dipping north under an angle of about 35 or 40 degrees. After crossing the river at the location of the old stamp mill, now destroyed by fire, we are at the foot of high vertical bluffs formed of fine-grained thinly bedded brown sandstones amounting to a belt several hundred feet in thickness. The top of the bluffs is formed by an overlying large belt of diabase interstratified with amygdaloidal seams. The upper strata of the sandstone belt on

the line of contact with the incumbent diabase are locally richly impregnated with copper, which strata were mined in connection with a transverse fissure vein intersecting the strata in this locality. The vein rock is calcspar in brecciated intermixture with fragments of the sandrock and diabase. The results of this mining were never satisfactory, and since more than 15 years, work has been abandoned there. Several other abandoned mining locations are four and five miles further west in the continuation of these high bluffs. These latter mining companies followed epidotic fissure veins charged with copper. The mining was done by driving horizontal drifts into the base of the diabase bluffs, which there sink down to a lower level in the valley than they do up at the Carp Lake mine.

A mile east of the Carp Lake mine the Cuyahoga mine worked one of the amygdaloidal belts interposed between the series of diabase rocks composing the summit portion of the shore range. The north slope of these hills is formed by a very large sedimentary belt several hundred feet in width, whose lower portion is a coarse conglomerate; the upper consists of brown colored sandrock beds with occasionally interlaminated narrower seams of coarse conglomeratic nature; the dip of these beds northward has an inclination from 30 to 35 degrees; the entire shore line from Union Bay to the mouth of Presque Isle River is formed by this belt. Numerous spar veins are seen to intersect it, but none of these was found to be copper-bearing or otherwise metalliferous. Many of these sandrock beds are plainly ripple-marked on the surface.

At the Union mine this sandrock belt forms the hanging of the amygdaloid belt mined in that locality. The amygdaloid makes part of a belt of diabasic rock ledges amounting to a thickness of from 300 to 400 feet, beneath which again a large belt of sandrock several hundred feet in thickness occurs, supposed to be the equivalent of the sandrock in the bluffs of the Carp mine. The bed of Union River presents an uninterrupted cross-section through the mentioned series of rocks. Of the succeeding strata southward, between Union mine and the Nonesuch location, the densely forest-covered condition of the country allows not often an exposure to be seen. A large belt of a red colored speckled amygdaloid, dipping only slightly inclined northward, is observable in the bed of a creek on the roadside between

the two mines; the densely crowded amygdules are filled with laumonite and calcspar. Parts of the belt are solid, another portion is a breccia with an abundance of sedimentary cement. The very frequent occurrence of such brecciated amygdaloid belts in all horizons of the group, suggests the sub-marine overflow of lava masses and the recementation of their vesiculous bursted and shattered superficial crust by sediments, after sufficient refrigeration and subsidence of ebullition.

The Nonesuch group next incumbent on the before described wide belt of brown sandrock and conglomerate beds which forms the north slope of the shore range between Union Bay and the mouth of Presque Isle River, locally reposes conformably on these strata, but in other places it is found in evident discordance with them and the other older members of the group. At the Nonesuch location this series of beds, as far as exposed, amounts to 400 or 500 feet of strata, dipping southeast under an angle of 30 degrees, while the closely adjoining trappean rock beds dip to the north; the immediate contact is not visible.

The group of strata seen there consists most of thinly bedded gray or bluish colored micaceo-argillitic sandrock ledges interstratified with slaty argillitic seams and with some thicker, more compact seams of sandstone, or also of a coarse conglomerate rock principally composed of porphyry pebbles. Single pebbles of porphyry are found scattered through all the beds.

Within this succession a seam of arenaceous rock about three or four feet wide is found richly impregnated with fine particles of metallic copper; more rarely heavier sheets of copper fill fissures in the ledges.

The percentage of copper in this seam is amply large enough to compare favorably with other profitably mined rock seams, but the fine comminution of the metal causes in the washing process a great loss, as the scaly particles float away with the sand, and several experiments to save this fine copper by chemical treatment of the stamped rock proved so far to be failures in economical respect.

North of the Nonesuch location, following the Little Iron River downward, the strata soon disappear under heavy drift masses, but reappear again about two miles from the shore on this creek and on Big Iron River. East of the Nonesuch mine

the belt continues to be exposed for about three miles and there in another mine, the White Pine location, the cupriferous seam is found to be equally rich in copper; also on Mineral River this cupriferous seam has been discovered in several localities.

Following the bed of Iron River from the Nonesuch mine, as before stated, the strata soon disappear under drift masses; about three miles down stream a belt of brown sandstone, trending east and west, is found crossing the river bed, dipping north under an angle of 50 degrees. The exposures continue for 100 steps, then at once without an interruption of the outcrops the sandrock beds apparently the same as the former trend northeast and southwest, dipping southeast under a much flatter angle, not over 25 degrees.

Two hundred steps further down, the same sort of brown sandstone beds has again an east and west trend and steep northern dip. After a short distance the outcrops disappear for the space of 145 steps along the river bed, then again the brown sandstones are largely exposed, trending northeast and dipping southeast under an angle of about 30 degrees. Several conglomerate seams are in this place interstratified with the sandrocks, amounting to 400 or 500 feet of strata. The lowest beds seen there resemble the cupriferous stratum of the Nonesuch mine. Further on, an abrupt change in the quality and position of the rock beds occurs, they trend east and west and dip north, first in very steep inclination, then gradually flattening their dip. The color of the very even-bedded arenaceous flagstones is bluish gray; onward the same beds continue, becoming almost horizontal with slight dip to the southeast; low falls about five feet high occur in this place, in the N. W. ¼ of Sec. 24, T. 51, R. 42. Some distance below, the strata dip under an angle of 15 or 20 degrees east, trend north and south, close to the north line of the section; the beds here are blue slate-rocks; they continue to be exposed for a long distance downward, retaining the same dip and strike, and amounting to a succession of several hundred feet of beds. Near the so called Scranton mine the strata dip southeast under low angle; lower down near the lake shore the same beds dip northwest very flat, locally almost horizontally. Underlying these beds we observe near the shore reddish brown colored sandstones, which are evidently the same as those exposed on the shore of Union Bay.

As my observations of this group along the valley of Big Iron River and Mineral River have been described previously in the third volume of the report, on pages 152 to 159, I refer the reader to them in order to avoid repetition.

On the east side of Iron River we find incumbent on the Nonesuch series a group of brown colored sandstones much more quartzose in composition than the darker tinged sandrocks of Union Bay, and not near as steeply inclined as they are; their dip is usually not over 15 degrees northward, and often less. This group of sandrocks borders the shore part of the country in a wide belt from Iron River to Portage Canal entry and farther north. They are the youngest deposits of the Keweenaw group, and their almost perfect resemblance to the so called eastern sandstones almost irresistibly impresses one with the idea of the uninterrupted succession of the Silurian sandrocks to the latest, considered to be Keweenawan. The probability of this is somewhat shaken by the structural features observed near the mouth of Montreal River and westward. The very large series of sandrocks exposed near the mouth of Montreal River in almost vertical position is found land-inward to be succeeded by a belt of gray sandrocks and slaty beds traceable from the mouth of Black River to the place where it intersects Montreal River, which is the analogon of the rock series of the Nonesuch mine.

The group of beds between this Nonesuch belt and the shore occupies the same relative position as the almost horizontal beds constituting the shore belt between the mouth of Iron River and Portage Canal entry, their analogy should therefore be expected, but by their flat dip and by their lithological character they approach much nearer to the horizontal sandstones of the Apostle Islands, which abut in great discordance against the sandstones of Montreal River, must therefore be younger, and great disturbances must have occurred between the deposition of the two.

But this unconformity is not necessarily a proof of a general break in the events and of a great lapse of time between the deposition of the Montreal River beds and those of the Apostle Islands. It proves only for this locality an excessive disturbance which caused discordance between the already formed strata and those later deposited, while not a great ways off towards the east the disturbance was more gentle and the deposits in these

places without suffering an abrupt break continued to form there without interruption, gradually lessening their inclination in the same measure as the upheaval subsided.

Taking in consideration the topographical position of the Nonesuch strata in the Portage Lake country and on the Ontonagon River and their distance from the shore where the nearly horizontal beds crop out, we find ample space left not only for the Montreal River sandstone series in its greatest display but also for an intermediate succession of strata linking these by gradual decrease in the dip with the horizontal sandstones on the shore.

The deeply drift-covered condition of this intervening space prevents the actual observation of this suggested uninterrupted succession, but no facts are known positively contradicting such suggestion of an uninterrupted formation of sediments in the same ocean basin from the time of the deposition of the Montreal River sandstones to the deposition of the so called western sandstones.

The similarity of the sandstones between Iron River and Portage Canal entry with the rocks composing the Apostle Islands is so great that I think it quite improbable to suppose a radical change in the conditions and a great lapse of time intervening between their deposition.

The proximate age of the upheaved upper Keweenawan rocks with the horizontal Silurian might also be inferred from the circumstance of the occurrence of small quantities of bituminous oil in the Nonesuch beds, as the first sign of organic life which henceforth developed itself more prolifically in the Silurian rocks. The sometimes steeply inclined position of the Nonesuch beds and their other times almost horizontal position observed in the Iron River district, shows clearly that local disturbances occurred at that time which could effect a discordance of contemporaneous strata, as we find it near Montreal River.

(6) GOGEBIC LAKE.

It remains yet for me to give a description of the copper-bearing rocks west of Gogebic Lake, but I have so far examined that formation only occasionally on its line of contact with the iron-bearing rock series.

The apparently conformable superposition of these diabasic overflows on the Huronian strata has been previously mentioned with the remark that different, higher or lower, beds of the latter group are found in contiguity with the diabases, which proves that an erosion of their surface must have occurred before they were covered with these overflows.

The majority of the diabasic rocks in contact with the iron-bearing strata have a porphyritic structure, consisting of a minutely crystalline groundmass in which large plagioclase crystals are abundantly dispersed in clusters. Copper is rarely found associated with these rocks, and then only in small quantities.

The very interesting Isle Royale likewise could not be described in this report, as I have not far enough advanced in its examination during the past season to be prepared for publication of the results.

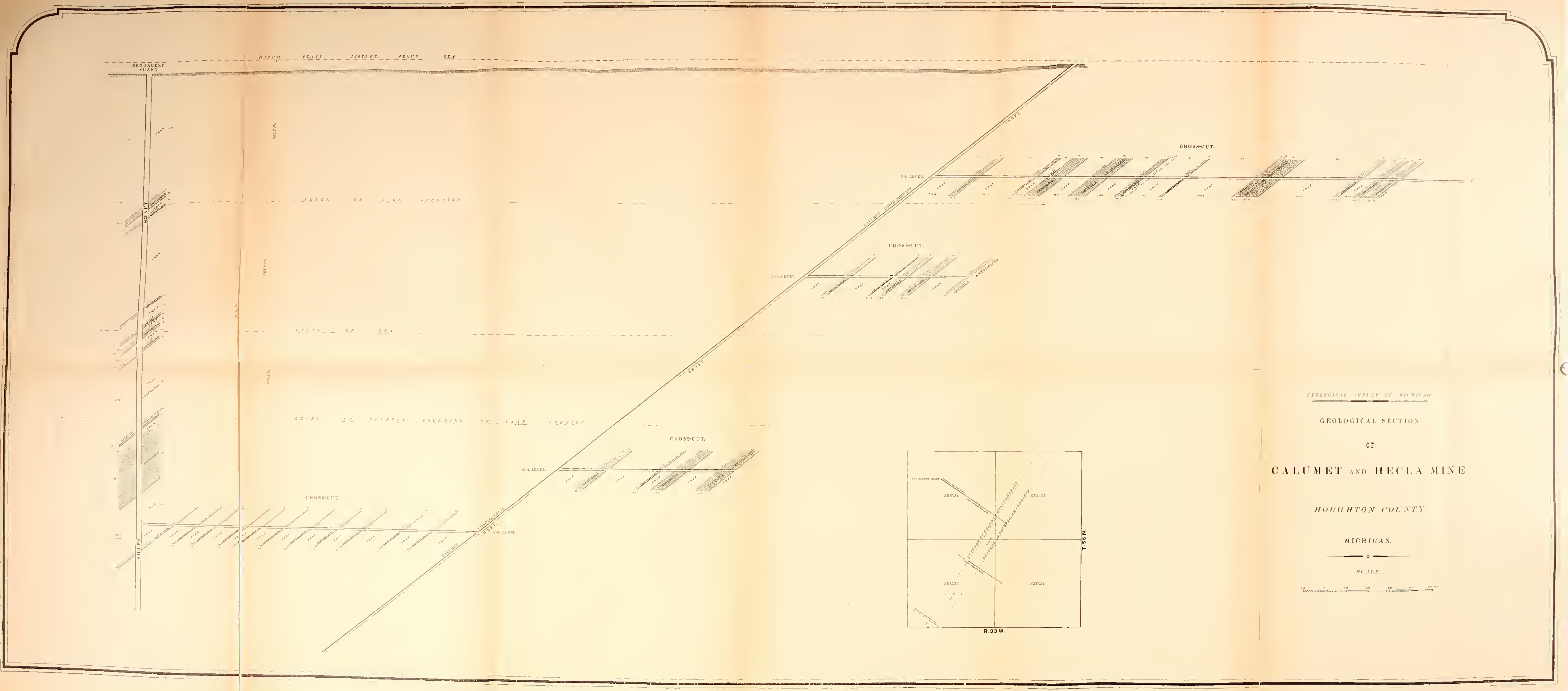
CROSS-SECTIONS.

On pages 112 and 113 of the foregoing report I have stated in foot notes that sections of Tamarack shafts, Nos. 3 and 4, and of the Calumet and Hecla mine would be substituted for the record mentioned by Dr. Rominger, which at the time the foot notes were inserted was not in my hands. The Tamarack record is complete to the latter part of March, 1894, and with the Calumet and Hecla record gives a cross-section of 8,400 feet horizontally, which represents 5,100 feet measured at right angles to the original surface of the beds. The distance between the Red Jacket shaft of the Calumet and Hecla mine and Tamarack No. 3, is about 1,300 feet. The observations in the two mines having been made by different persons, it is not strange that trap and amygdaloid beds do not show a closer correspondence in the two vertical shafts, even if allowance be made for local irregularities. On the other hand, the same beds in different shafts or cross-cuts of the same mine show a noticeable persistence.

A comparison of the conglomerate beds shown in these cross-cuts with those figured by Marvine, in Volume I of these reports, makes it probable that we have here, next above the Calumet conglomerate, the Allouez conglomerate, Marvine's No. 15, as well as his Nos. 16 and 17, all of which, at Calumet, are thicker than at Eagle River. Marvine's bed No. 14, the Houghton conglomerate, is wanting in both mines, and his No. 12, the North Star conglomerate, which would occur next below the Calumet conglomerate, is not found in the Calumet and Hecla Mine. The conglomerate beds being nearer together than at Eagle River, show a convergence towards the southwest, *i. e.*, a thinning of the intermediate eruptives, which confirms Marvine's observations.

L. L. HUBBARD.

Houghton, May, 1894.



RED JACKET SHAFT
SHAFT
CROSS-CUT
CROSS-CUT
CROSS-CUT
CROSS-CUT
CALUMET CONGLOMERATE
GEOLOGICAL SURVEY OF MICHIGAN.
GEOLOGICAL SECTION
OF
CALUMET AND HECLA MINE
HOUGHTON COUNTY
MICHIGAN.
SCALE.
T. 56 N.
R. 33 W.

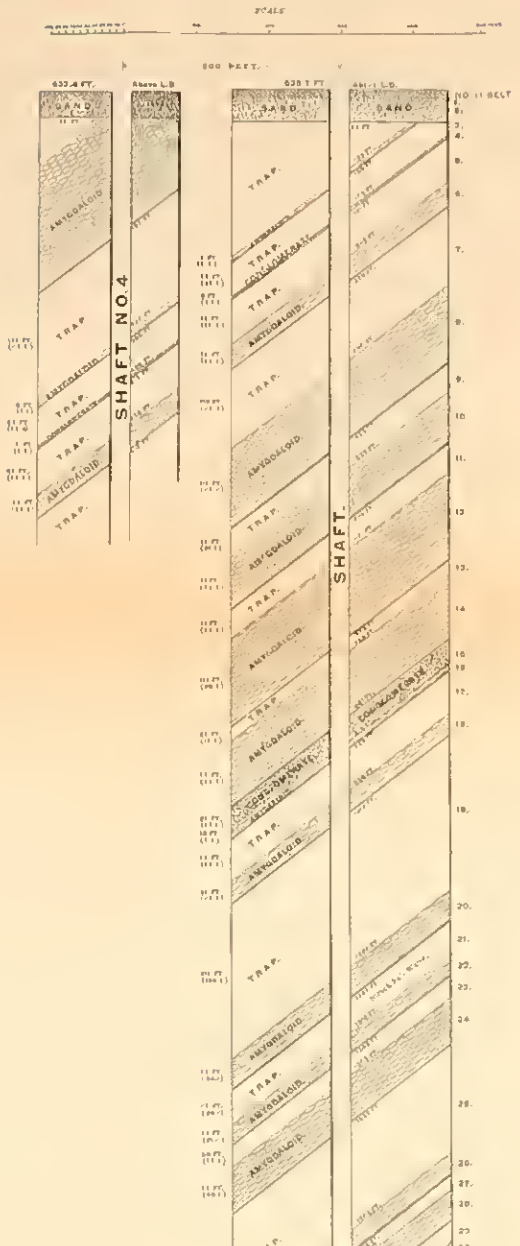
GEOLOGICAL SECTION

OF

NORTH TAMARACK SHAFT, NO. 3.

HOUGHTON COUNTY

MICHIGAN.



NOTE:

INDEX.

Actinolite 69
Actinolite schist. See SCHIST.
Adventure Mine 149
Ætna Mine 143
Agate 93, 144
Agate Bay 56, 59, 60, 89
Ahmeek Mine 114, 120
Albany and **Boston** Mine 101, 108, 109, 110
Albany and **Boston** conglomerate 101, 116
Allouez Mine 108, 118, 119, 120
Allouez conglomerate 108, 110, 113, 118, 119, 122, 128, 129, 142, 144
See also Albany and Boston conglomerate.
Distance of, above Calumet conglomerate at Allouez Mine 108
Distance of, above Calumet conglomerate on Kearsarge Location 117
Distance of, above Osceola amygdaloid at Osceola Mine 110
Thickness of 108
Amygdaloid 48, 86, 95, 96, 123, 127, 131, 132, 135, 137, 138
Alteration of 127
of Atlantic Mine 97
belt, "Outer," above the "great" conglomerate 127
Boulders of, in conglomerate breccia. See BRECCIA. 115
of Cliff Mine 122
Cupriferous 94, 99, 101, 102, 109, 117, 125
of Delaware Mine 130
Amygdaloid, Epidotic 95, 96, 100, 118
of "East" vein 144
the foamy part of a lava flow 93
hanging wall of Calumet conglomerate 111, 113
Olivine-bearing 111, 112
of the Ontonagon region 146, 147, 148, 149, 150
Relation of, to diabase 93
Relation of, to pseudo-amygdaloid 119
of Star Mine 142
"veins" of the Ontonagon region 148
Amygdaloidal cavities in breccia 98, 136
Amygdules, Material of 93, 103, 109
Analcite 93, 109, 121, 129, 143
Red 127
Analyses of iron-ore 28, 43, 48, 51, 54, 77
Apatite, in gabbro 132
in olivine-diabases 124
Apophyllite 121, 129
Apostle Islands, Sandstones of the 89, 162, 163
Arcadian Mine 100
Archæan 1, 2
Argillite, associated with slates of Huron Bay 65
of the Felch Mountain district 32, 35
of the Marquette region 72
of the Michigamme River 37
of the Gogebic region 50
of the Quinnesec district 73
near the Taylor mine 62, 63
Schist. See SCHIST.

Ashbed 103, 119, 126, 127
Dip of, at Copper Falls Mine 125
Width of, at " " " 125
Atlantic Mine 93, 94, 95, 97, 98, 99, 102, 103
Atlantic stamp mill 96
Augite, Alteration of 94
Alteration of, to hornblende 14, 18, 132
Alteration of, to steatite-like mineral 132
Alteration of, to viridite 65
Augite, in diabase dykes 6, 52, 65, 111, 120, 143
in lustre-mottled diabase 113, 119, 124, 132
in melaphyr 17
as an original constituent of diorite 14
Azurite 118
Azoic 1, 2
Bad River, Wisconsin 10, 55
Badwater Village 35, 37, 81
Barrel-Copper 94, 111, 118
Bayfield Peninsula, Wisconsin, Keweenawan, of 86
Belt Mine 150, 151
Bête Grise Bay 107, 134
Big Iron River 160, 162
Biotite, in chloritoid-rock 31
replacing hornblende 6
Bituminous Oil 163
Black Bay 86
Black River 162
Bohemian Mountain 131, 134
Bohemian Mine 150
Bohemian Range 107, 110, 141, 154, 155, 156
Porphyries of the 110
Bordman, Mr. 36, 76, 83
Boston Mine, Marquette region 21
Keweenaw Point 142
Boulder Drift 40
Breccia 43, 84
Amygdaloidal 95, 96, 97, 102, 103, 105, 109, 113, 143, 147, 157, 158
Amygdaloidal, Origin of 160
of crystalline schists 69
of diabase 112
of diorite 19, 22, 23, 44, 46
of felsite 136, 137, 138, 139, 140
of granite 4, 66
Breccia of mica-schist 22, 57, 58, 79
in ore formation 53
of quartz 52, 65
of quartzite 44, 45, 47, 67, 71
Sedimentary origin of 96
as vein-matter 121, 127
Breen Mines, Fossils in 90
Breitung, Mr. 36
Briar Hill Iron Company 75
Brockaway, Mr. 122
Brooks, Major T. B. 29, 39, 78
Brotherton, Mr. 35, 38
Brule River 81, 82
Calcspar 27, 129, 134, 141, 143
alteration product in diorite 13
Amygdules of 93, 95, 97, 99, 109, 110, 113, 118, 126, 131
associated with amygdaloids 94, 99, 101, 102, 103, 109, 110, 112, 118, 149
associated with manganese 144
cement 19, 96, 113
Concretions of 80
in fissure veins 97, 105, 111, 121, 123, 127, 129, 141, 142, 143
Seams of, in diabase 137, 138
Vein of, in Atlantic Mine 97
Calumet and **Hecla** Mine, Cross-section in 91, 108, 114, 165
Calumet Conglomerate 108, 111, 113, 114, 115, 118, 122, 123, 128, 130, 135
Groundmass of 115
Hanging wall of 116
Pebbles of 107, 115, 116
Richness of 117
Cannon Mine 23, 25
Carp River 140, 155, 158
Carp Lake 158
Carp Mine 159
Cascade River 152
Centennial Mine. See Schoolcraft Mine.
Central Mine 128, 129, 130
Occurrence of copper in 129
Chalcedony 44, 47, 93, 103, 140
Chalcocite 94, 99, 134
Champion Furnace 69, 80
Champion Mine 30, 31, 67, 69, 80
Champion Vein, Ontonagon region 149, 150
Chert 29, 33, 71, 73, 78

Cheshire Mine....61, 70, 71
Chicagon Lake....75, 84
Chippewa Mine....25
Chlorite....63, 93, 102, 113, 116, 132, 143
Alteration product of augite....124
Chlorite Schist....37
Chloritic Mineral, decomposition product of hornblende....13
Chloritoid....30, 31
Clark Mine....142, 143
Clarksburg....69, 70
Cliff Mine....119, 121, 122, 127, 142, 157
Cross-section east of....122, 123
Commonwealth Mine....36, 37, 83
Commonwealth Group, superimposed on mica-schist....83, 84
Concretions in felsite....139
Concord Mine....100
Conglomerate Mine....129
Conglomerates, Amygdaloidal....105, 126, 136, 137, 138, 139
of the Gogebic region....44
west of Huron Creek....96
in drift....99, 130
with eastern sandstones....105
Granite-....4, 9
of Keweenaw Point....98, 99, 100, 102, 103, 104, 125, 131, 134, 136, 137, 138, 144
of Keweenaw Point, Cement of....105, 115, 120, 134
of Keweenaw Point, "The great"....104, 119, 125, 126, 127, 143, 144, 145
of Keweenaw Point, Width of....92
of the Ontonagon region....146, 147, 148, 160, 161
Pebbles in. See PEBBLES.
Seams of....147
See Albany and Boston, Allouez, Calumet, Houghton, Kearsarge and Kingston.
Contact of sandstone and amygdaloid on Sec. 6, T. 54, R. 33....92
of sandstone and trap on Bête Grise Bay....107
of sandstone and trap in Hungarian Creek....105
of Silurian and Keweenawan....92, 107, 134, 135, 136
Copper, Amygdules of....93, 109, 149
Copper, associated with amygdaloids....102, 111, 112, 142
Black oxide of....144
deposited by galvanism....121
in amygdaloids cut by fissure veins....122
in calcite....111
in conglomerate....113, 115, 116, 120, 128, 130
in fissure veins....105, 127, 141
in hanging wall of Calumet conglomerate....113
in hanging wall of Osceola amygdaloid....113
masses....101, 148, 149
Minerals associated with....129
Mode of occurrence of....97, 99, 100, 101, 112, 129, 140, 143, 149, 160
Pseudomorphs of, after laumonite....110
Red oxide of....118, 136, 140, 148
Copper-bearing Group. See Keweenawan and Keweenaw Group.
Copper-bearing Rock....88
Copper District described by Pumpelly....90
Copper Falls Mine....125, 127
Copper Harbor....144
Copper Range....99
Greenstones of the....6
west of Gogebic Lake....87
Crawford, Jas....117
Credner, H....15
Cross-section, Calumet and Hecla Mine....91, 108, 114, 165
Cliff Mine....122
Isle Royal Mine....92, 102
Phœnix Mine, Eagle Riv....123, 125
Peninsula Mine....165
Tamarack Mine....113, 165
Crystal Falls....74, 75, 76, 81
Cuprite. See copper, Red oxide of.
Cuyahoga Mine....159
Dalliba Mine....61, 67, 69
Dana, Prof. J. D....1, 30
Daniell, John....111, 112
Datolite, Amygdules of....93, 99, 103, 110, 126, 142
associated with amygdaloids....101, 110, 149

Datolite, in fissure veins 105, 121, 127, 129, 143
Delaware Mine 129, 130, 134, 144
Delessite, Amygdules of 93, 97, 98, 100, 102, 109, 110, 113, 118, 120, 126, 131, 138
associated with amygdaloids 118, 127
a decomposition product of olivine 143
in diabase 144
Devil's Island 80
Diabase, Ashbed 119
Diabase, Agatiferous, of Copper Harbor 144
Boulders of, in conglomerate 115
Coarsely crystalline, characteristic of Greenstone Range 143
Composition of 52, 93, 101
foot-wall of manganese bed at Copper Harbor 144
hanging wall of Osceola amygdaloid 111
intrusive in diorite 38
intrusive in granite 5
See also DYKES.
Joint planes of 116
Knob of 63, 155
Lustre-mottled 102, 113, 119, 124, 131, 132, 133, 136, 138
Olivine-bearing 80, 102, 111, 157
Paramorphosis of 11
Porphyritic 48, 138, 139, 157
Pseudo-amygdaloidal 119
Red 158
Uralitic 17, 18
Diabase Belts, at Atlantic Mine 98
of Bohemian Mountain 134
at Cliff Mine 122
south of Cliff Mine 123
at Copper Falls 127
in Douglass Houghton Creek 106
at Eagle Harbor, north of the "great" conglomerate 126
of Eagle River cross-section 125
Epidotic 132
west of Hancock Mine 103
in Huron Creek 96
at Kearsarge Mine 118
of Keweenaw Mine 142
Diabase Belts, of Little Montreal River 137
in Tamarack shaft No. 1 112
of Thunder Bay, overlying schist 89
of Union Bay 141
in West Houghton 95
Diabase, Keweenawan 20, 40, 45, 48, 55, 60, 85, 103
Contact of, with Huronian 87
characterized by serpentine-like mineral 124
of Thunder Bay 88
less disturbed than Huronian 87
Diallage 15, 16
Dikelocephalus, in sandstone at Breen Mines 90
Diorite 11–20, 22, 25, 43, 46, 53, 71, 72, 73, 83
Absence of, in granite of Mesaba Heights 60
Augitiferous 14
Contact of, with micaceous schist 41
enclosing iron ore deposits 37
Eruptive 19, 24, 82
intruded by granite, contemporaneously with upheaval of latter 3
intrusive in granite 5, 12, 73
intrusive in granite, lithologically identical with diorites of Huronian Group 5
intrusive in iron-bearing formation 56
Massive 3, 5, 10, 38, 42
Microscopical character of 12, 13
of Quinnesec Falls 15
Schistose 3, 4, 5, 9, 38, 42, 44
underlying iron formation 10, 19, 32, 50
Uralitic, intersecting ordinary diorite 12
uralitic, Microscopical character of 17, 18
Dip, of Allouez conglomerate at Allouez Mine 118
of Calumet conglomerate at Calumet and Hecla Mine 114
of conglomerate between Rockland and Ontonagon 146

Dip, of eastern sandstone. S. 29, T. 58, R. 28 136
of felsite. S. 30, T. 58, R. 27 139
of graphitic slates of the Taylor Mine 62
of iron-bearing series, T. 41, R. 30 36
of iron-bearing series, T. 46, R. 30 22
of iron-bearing series, S. 33, T. 42, R. 28 8
of iron-bearing series, Felch Mountain Range 32
of iron-bearing series at Gogogashung River 53
of iron-bearing series east of Michigamme 67
of iron-bearing series near Sunday Lake 49
of iron-bearing series at Vermillion Lake, Minnesota 57
of Keweenaw series at Atlantic Mine 97
of Keweenaw series at Bête Grise Bay 107
of Keweenaw series at Calumet Mine 88
of Keweenaw series on Cascade River 152
of Keweenaw series at Carp Lake 158
of Keweenaw series at Cliff Mine 121
of Keweenaw series at Copper Falls Mine 127
of Keweenaw series at Delaware Mine 130
of Keweenaw series at Douglass Houghton Creek 105
of Keweenaw series at Gogebic Lake 88
of Keweenaw series at Houghton 92
of Keweenaw series at Hungarian Creek 104
of Keweenaw series near end of Keweenaw Point 88
of Keweenaw series at Minnesota Mine 88
of Keweenaw series near Montreal River 88
Dip, of Keweenaw series near Portage Lake 88
of Keweenaw series in the Quincy Mine 101
of Keweenaw series at Swede Creek 92
of Knowlton vein at Mass Mine 150
of magnetic schist in contact with Keweenawan diabase, S. 10, T. 47, R. 45 48
of manganese ore belt at Copper Harbor 144
of mica-schist at mouth of Paint River 82
of Osceola amygdaloid at Osceola Mine 110
of sandstone west of Atlantic Stamp Mill 98
of sandstone at Bête Grise Bay 134
of sandstone in Douglass Houghton Creek 106
of sandstone, on Iron River, three miles below Nonesuch Mine 161
of sandstone between Iron River and Portage Canal 162
of sandstone on S. 28, T. 55, R. 34 103
of sandstone (western) near Portage Lake Canal 89, 90
of strata at Cuyahoga Mine 159
of strata at Forest Mine 151
of strata at Magnetic Mine 26
of strata between Mesaba Heights and Lake Supe'r 60
of strata on islands in Michigamme Lake 79
of strata west of Lake Michigamme 66
of strata at Nonesuch Mine 160
of strata in S. 33, T. 44, R. 31 38
Dislocation of strata at Erie Mine 24
Disturbance of Huronian strata 87, 88
Dolerite 6, 21, 22
Dolomite, near Champion Mine 69
Dorchester Mine 108
Douglass Mine 100
Douglass Houghton Cr'k 104, 105, 107
Drift 87

Drill-holes in Keweenawan, south of Cliff Mine 122
Duluth, Minnesota, Gabbro cut by diabase dykes, at 6
Gabbro cut by granitic dykes at 4, 154
Keweenawan, at 86
Olivine-gabbro, at 133
Dykes, Diabasic 5, 6, 38, 52, 60, 62, 63, 65, 66, 70, 80
Dioritic 5, 24
Dioritic, older than diabasic 5
Doleritic 6, 21
Granitic 7, 10, 23
Porphyritic 7, 154
cutting iron series 7
cutting slate 65
of serpentine 15
Eagle Harbor 126
Eagle River District 90, 103, 119, 125, 126, 128, 145
"East" Vein 143
Edwards Mine 30, 31
Edwards, R. M. 112
Ellwood Mine 37, 83
Eozoic 1, 2
Epidote, Amygdules of 93, 95, 97, 109, 110, 113, 118, 131
associated with amygdaloids 99, 100, 101, 109, 110, 118, 138, 149
as cement 130
a decomposition product in diabase 94
a decomposition product in diorite 13
a decomposition product in porphyry 116
in gabbro 132
as vein-matter 121, 143
Erie Mine 23, 24, 25, 26, 27, 28
Escanaba River 69, 70, 71, 72
Evergreen Belt 150, 151
Evergreen Vein 149
Excelsior Mine 21
Exploring Pits between Grand Portage & Atlantic Mines 95
west of Houghton bridge 95, 96
west of Michigamme Lake 66
Felch Mountain 35
Felch Mountain district 7
range 32, 35
ore formation 34, 36, 44
Feldspar (orthoclase), in amygdaloid 109
in Ashbed rock 126
in breccia 84, 118, 137
in chloritoid rock 31
in diabase 97, 102, 124, 143
in porphyritic diabase 138
in diorite, altered 38
in felsite 140, 141
in fissures 111, 121
in gabbro 132, 133
in gneissoid rock 28
in recomposed granite 9
in melaphyr 17
in mica-schist 63, 82
in pebbles of conglomerate 97, 115, 116
in porphyry 110, 125
in sandstone 98
(plagioclase), in amygdaloid 102
in diabase 6, 21, 38, 52, 65, 93, 101, 111, 113, 119, 120, 124, 125, 132
in diorite 12, 13, 14, 19
in gabbro 15, 133
Felsite 97, 136, 137, 138, 139, 141, 153, 156, 157, 158
Amygdaloidal 140
breccia 136, 137
Eruptive origin of 141
Microscopical character of 135
of Mount Houghton 135, 136
Ferro-Dolomite 52
Fire Steel River 150
Fissure Vein 94, 120, 127, 129, 134, 141, 142, 143, 144, 148, 151, 152, 159
Minerals of 105, 143
Flagstones 47, 52, 77
Flint Steel River 146
Florence Mine 83
Flow-Structure 19
Folds in strata 62, 79
Forest Mine 151
Fort Wilkins 144
Foster and Whitney 1, 90
Franklin Mine 100, 101, 108, 109
Gabbro 4, 6, 14, 15, 97, 132, 133
contemporaneous with diorite 14, 15
of Sturgeon Falls 15
of Minnesota 60

Gabbro, orthoclase, Decomposition product of 133
younger than Huronian 4
Galena 9, 19, 44, 45
Garden City Mine 126, 127
Garnets 26, 29, 84
Geological reports of Wisconsin 53
Geologists of Wisconsin 10
Gillis, Mr. 19, 44, 47, 56
Girard Mine 138, 142
Gneiss 5
Gneissoid rocks 1, 2, 25, 28
in drift 40
Goethite 68, 71, 72, 75
Gogebic Iron range, Granites of 8
Gogebic Lake 9, 39, 40, 44, 56, 84, 87, 88, 145, 151, 163
Gogebic region 39, 53
Analogy of, with Marquette and Menominee regions 19
Schists of 84
Porphyritic diabase of 138
Gogogashung River 10, 53, 54
Gottstein, P. 95
Grand Portage Mine 94, 95
Granite 1-10, 25, 38, 44, 49, 50, 52, 63, 64
in contact with Huronian 4, 23, 32
in contact with limestone 34
Decomposition of 73
intruded by diorite 5, 9, 12, 73
intrusive in diorite 3
intrusive in Huronian 8
See also DYKES.
intrusive in rocks younger than iron-bearing group 4
of Mesaba Heights, Minnesota 60
Proximity of, to iron-formation 10
Recomposed 9, 63
underlying diorite 19
underlying graphite-schist 73
Grape Ore 50, 51, 54, 74
Graphite 45
Graphite-Slate. See SLATE.
Greenstone 6, 121, 124
Greenstone Range 117, 119, 120, 122, 129, 142, 143, 144
Composition of 124
Thickness of 124
Hancock Amygdaloid 102
Mine 102, 103
Hematite Deposits, in arenaceous slate group 61, 62
of Gogebic region 48, 50, 51, 52, 56
of Marquette region 3, 21, 22, 23, 62
of Menominee region 36, 38, 75, 83
in roofing-slates 65
with slate and quartzite 70
Hematite, Soft 36, 63, 74, 77
Manganiferous, of Jackson mine 22
Pseudomorphs of, after siderite 65
Hill's Creek 104
Hornblende, Alteration of, to viridite 13
in breccia 24
in diorite 5, 12, 13, 14, 15, 17, 18
Fibrous structure of, in diorite 13
in gneissoid rock 8, 28
in granitic rock 5
rock, Garnetiferous 26
in schist of Michigamme Lake 80
Hornblende Schist. See SCHIST.
Houghton Conglomerate 101, 110, 128, 130
Hungarian Creek 104
Huron Bay 60, 65, 81, 84
Huron Mine 94
Huron Creek 96
Huronian 1-6, 19, 21, 40, 54, 55, 60, 61, 65, 73, 78, 86, 87, 88, 89, 164
Conformity of, with Keweenawan 45, 49, 87
cut by dykes 6
Disturbance of 88
Disturbance of, in contact with granite 4
Erosion of 87
principally diorite 12
Subdivision of 11
Upheaval of 87
Hydro-Mica (Sericite), abundant in dioritic schists 14

Hydro-Mica (Sericite), an alteration product of hornblende 13
associated with chloritoid 31
See MICA, SCHIST, etc.
Hydro-micaceous. See SCHIST.
Iron-bearing Formation, of Gogebic region, Slate constituting upper horizon of 56
at Gogogashung River, Wisconsin 53
Intrusion of, by granite 8
of Mesaba Heights, Minnesota 59
of Penokee Gap, Wisconsin 55
of the Penokee-Gogebic region, Little disturbance of 88
Probable age of 36
Strata above the, at Champion Mine, very thick 69
Synclinal trough of, west of Excelsior Mine 21
Unconformity of, with Potsdam sandstone in Menominee region 90
underlain by diorite 10, 19, 32, 50
underlain by kaolinitic rock 10
of Vermillion Lake, Minnesota 60
Iron Ore, Analyses of 28, 43, 48, 51, 54, 77
Secondary infiltration of 37, 50
Iron Ore Deposits, of arenaceous slate group 61
of Crystal Falls 74
of Gogebic District, younger than Marquette and Felch Mountain deposits 44
of Minnesota 56–60
of Paint River 75
Relative ages of 28
of T. 43, R. 35 77
of T. 46, R. 42 42
Transition from slate to mica-schist 24
in Upper Huronian 73
of Wisconsin 53, 54
Iron-ore Group, Lower 21–60
of Gogebic District 39–53
Iron Pyrites in diorite 13
in slate 74
Iron River 75, 76, 77, 84, 145, 154, 155, 161, 162, 163
Irving, R. D. 88, 106, 132, 140
Isle Royale 86, 139, 164
Isle Royale Mining Company 92, 93, 94, 99, 100, 102
Jackson, C. T. 90
Jackson Mine 22
Jasper-banded Ore 23, 35, 48, 49, 50, 52, 56, 57, 58, 62, 63, 64, 67, 71
Jaspery Rock, at Tamarack shaft 112
in drill hole at South Cliff Mine 122
Joint Planes in diabase 112, 116
Kaolinite 10, 21, 38, 73, 82, 140
Kearsarge Amygdaloid 117, 118
Distance of, from Calumet conglomerate 117
Distance of, from Kearsarge conglomerate 117
Kearsarge Conglomerate 117, 118, 120, 123
Foot-wall of 120
Hanging-wall of 120
Kearsarge Mine 114
Keweenaw Group 1, 85–88
Abnormal position of Eastern sandstone near 106
Absence of, east of Keweenaw Point 86
on Bayfield Peninsula 86
of Canadian Geologists 88
Conformability of, with Huronian 45, 49, 87
Diabase of 20, 40, 45, 48, 55, 60, 85, 93, 103, 154
at Duluth, Minnesota 154
Gabbro at base of 6
General structure of 88
Lower division of 134
Unconformability of, with sandstone 87, 89, 104, 134
Upper limits of 89
Width of, at Portage Lake 92
Width of, on Keweenaw Point 92
Keweenaw Mine 142
Keweenaw Peninsula, Cross-section of 91
Sandstones and conglomerates of 89, 98, 112
Thickness of strata of 91, 92
Keweenaw Period 87
Keweenawan, Age of 163

Keweenawan, Disturbance of 88
Position of, on Keweenaw Point 87
Keyes Lake 37, 83
Keystone Mine 79, 80, 81
Kingston Conglomerate 118
Kloman Mine 22
Knowlton Mine 149
Knowlton Vein 148, 149, 150
Lac La Belle 124, 130, 131, 134
Lake Mary 37
Lake Superior, described by Jackson and others 90
Lake Superior Basin 86
L'Anse, Slate formation of 60, 64, 81
L'Anse Bay, Sandstones of 104
Lanmonite, Amygdules of 93, 94, 96, 97, 102, 109, 113, 118, 126
associated with amygdaloids 101, 102, 109
as cement 96, 113
in fissure veins 121, 127, 129, 141, 142, 143
rock of Albany and Boston Mine 110
Seams of, in diabase 137, 138
Laurentian 1–10
Lighthouse Point, Marquette 7
Lingula Shells in sandstone at the Breen Mine 90
Limestone 10, 34, 38, 39, 44, 46, 70
Drift masses of 34
of iron-formation of Felch Mountain district 32, 33
of Marquette region 3
of Menominee region 36, 73
of Michigamme River 39
of Penokee Gap 55
Limonite 10, 29, 37, 50, 56, 62, 63, 64, 66, 70, 71, 73, 74, 75, 77, 78, 83
Limonite, in arenaceous slate group 61
Little Carp River 158
Little Iron River 155, 160
Little Lake, Marquette region 71
Little Montreal River 134, 136, 137, 142
Little Presque Isle River 46
Lonsdorf, Mr. 72
Mabbs Vein 102
Magnetic Schist. See SCHIST.
Magnetite, associated with actinolite 26, 80
Magnetite, associated with augite in amygdaloid 102
associated with olivine in diabase 120, 124, 132
a component of schists 43, 56, 80
in felsite 135
Granules of, in chloritoid-rock 31
Occurrence of, in the Gogebic region 47
Occurrence of, in the Marquette region 21
in orthoclase-gabbro 132, 133
replacing titan-iron in diorite 13
in slate 61
in thin sections under microscope 6, 28, 101, 111, 114
Magnetic Mine 26, 27, 28, 29, 43, 79, 80
Malachite 118, 131, 136, 140, 148
Mamainse Point 86
Manganese, associated with iron, 22, 51, 52, 62
Deposit of, at Copper Harbor 144
Maple Grove 146
Marble 32
Marquette, Geological structure of environs of 3, 7
Marquette Region, Ore deposits of 21–31
Disturbance of Huronian formation in 88
Relative age of ore deposits of 44
Martite 55, 58, 71, 135
Marvine, A. R. 91, 123
Marvine's cross-section at Eagle River 125
Mass Mine 149
Mass Vein 149
McKennan, Mr. 77
Mendota Mine 124, 131, 133
Menominee Region 31–39
Staurolitiferous mica-schist of the 84
Eastern sandstone of the 90
Menominee River 16, 36, 37
Mesaba Heights, Minnesota 59, 60
Mesnard Mine 108
Melaphyr Microscopical character of 16, 17

Metropolitan Mine 7, 34
Mica, derivation product of hornblende 13
replacing iron-ore 24
Michigamme 30, 31
Michigamme Lake 21, 66, 78, 79, 80, 84
Islands in 79
Michigamme Mine 28, 29, 30, 43, 78
Succession of strata at 29
Michigamme River 36, 38, 39, 81
Michigan Geological Reports 39
Michigan Mine 142
Michipicoten Island 86
Mineral River 161, 162
Minnesota Mine 145, 147, 148, 151
Mitchell, P. 42
Montezuma Mine 95
Montreal River 10, 40, 50, 52, 53, 55, 56, 87, 88, 89, 162, 163
Moore, Captain 50, 51
Mosquito Lake 144
Mount Houghton, Formations of 131, 133, 135, 138
National Mine 147, 148
Natrolite 127, 129
Negaunee, Augite-diorite of 14
Mining district of 21
Negaunee Furnace 22
New England Mine 139
New York Mine 142
Nipigon Bay 86
Nonesuch Group 103, 157, 160, 162, 163
Nonesuch Mine 145, 146, 155, 159, 161, 162
Northampton Belt 69
Northampton Mine 36, 61, 67, 80
Quartzite beds of 68
North Cliff Mine 126
North Star Conglomerate 100
North Star Mining Company 100, 101
Norwich Mine 151
Novaculite 38
Ochre 70
Ogema Vein 149, 150
Old Phœnix Mine 124, 125, 126, 132
Olivine, Alteration of 119, 124, 143
in diabase 6, 52, 80, 112, 132
gabbro 133
inclosed by augite 17
Ontonagon Region 145
Nonesuch series in the 103
Ontonagon River 87, 145, 163
Ore-deposits, Penokee-Gogebic, Marquette, Felch Mt., Relative ages of 44
Orthoclase, Amygdules of 100, 109
in gabbro 102
Osceola Amygdaloid 110, 114, 123
Character and composition of 110, 111
Width of 110
Distance of, east of Calumet conglomerate 108, 110
Hanging-wall of 113
Osceola Mine 108, 110, 111, 112
Overturn of strata in T. 41, R. 30 36
Paint River 36, 37, 74, 75, 81, 82, 84
Pease, Captain 50, 51
Pebbles in conglomerate 96, 105, 109, 115, 120, 125, 126, 138
penetrated by copper 116
Pemenee Falls 7, 16
Peninsula Mine 108
See also ALBANY and BOSTON MINE.
Penokee Range 4, 9, 40
Penokee Gap 10, 44, 54, 55, 56
Penokee-Gogebic Region, Ore formation of 44, 88
Olivine-gabbro of 133
Wisconsin 53
Pewabic Mine 100, 101, 108, 109, 110
Pewabic-Franklin-Quincy Mines, Amygdaloid of 101, 108, 109
Philadelphia Mine 142
Phœnix Mine 91, 128, 129
See also OLD PHŒNIX Mine.
Pigeon River 86
Plumbago Creek 63, 64
Porcupine Mountains 87
Amygdaloidal felsite of 140
Felsite of 154
Quartz-porphyry of 141
Porphyries of Bohemian Range 110
Porphyrite 16
Porphyritic Rock 109
Porphyry 85, 116, 133
Boulders of, in drift 40
Igneous origin of 154
pebbles, Composition of 116
Quartz- 107, 135, 141, 146, 152, 153, 154
Portage Lake 90, 98, 100, 103, 108, 145
canal 87, 145

Portage Lake, Sandstone at 103, 162, 163
Portage Lake fault 92
Olivine-free diabases of 102
Potsdam Sandstone 90
Prehnite, Amygdules of 93, 97, 99, 109, 110, 142
Associated with amygdaloids 101, 102, 109, 110, 111, 149
in fissure veins 105, 110, 111, 121, 123, 127, 129, 141, 143
Pseudo-amygdules of 143
Presque Isle River 45, 56, 159, 160
Protogine 38
Psendo-Amygdaloid 109, 119, 120
Pseudo-Amygdules 93, 124, 143
Pumpelly, R. 15, 39, 90, 91, 92, 95, 109, 116, 123, 124
Pyrolusite 51, 52, 62
Quarry, Gabbro 60
Sandstone 107
Quartz, Amygdules of 93, 97, 109, 110, 113, 126, 129
associated with amygdaloids 101, 103, 110, 118, 140
associated with copper-masses 129
in felsite of Mt. Houghton 136
in fissure veins 94, 143
Gold-bearing 42
in orthoclase gabbro 132
porphyry 107, 135, 141, 146, 152, 153, 154
Seams of, in limestone 36
Quartzite 32, 35, 45, 49
beds of Northampton Mine 68
breccia 9, 44, 47
formation, T. 47, R. 25 9
Galena-bearing 44, 45, 46
Granular 58, 65, 66, 71
of iron-ore formation 10, 22, 33, 38, 49, 52, 53, 54, 55, 65, 67, 70, 83
Micaceous 25, 36, 73
resting on granite 9, 27
in Standard Mine 23
Quinnesec Falls 7, 15
Quinnesec Mines, Fossils in sandstone of 90
Quinnesec Range 34, 38, 44
Unbroken continuity of strata of 73
Quincy Mine 101, 102, 109
Quiver Falls 14
Republic Mine 22, 25, 26, 28
Ripple Marks 116, 135
Ridge Mine 149
Roofing-Slates 65, 66
Rubellan, paramorphic product of olivine 114
Ryan, E. 99
Sahlite 18, 32
St. Clair Mine 128
St. Croix River 86, 90
St. Louis River 60
St. Mary's Mine 108
Sandstones, Coarse grained 103
in conglomerate 116
Eastern 89, 90, 105, 106, 136, 162
Contact of, with diabase at Bête Grise Bay 135
Dip of 134, 136
filling crevices in diabase 136
Fine-grained 158
of Keweenaw Point 98, 143, 145, 146
Micaceous 103
Ontonagon, Dip of 145
Potsdam 90
Silurian, 34, 35, 39, 86, 87, 90, 92, 104, 107, 148, 151, 156, 162, 163
Western 89, 90, 98, 163
Sault Ste. Mary's canal 156
Schist, Argillitic 72, 73
of Menominee region 37
Biotite, Garnetiferous 79
Chlorite 37
Dioritic 3, 4, 5, 9, 38, 42, 44
Eruptive origin of 5
Folded 3
Graphitic, of Gogebic region 47
Graphitic, of Marquette region 29, 62, 63, 66, 67, 68, 69, 72, 73, 78
of Menominee region 37, 73, 74, 76, 83
Hornblende 5, 8, 24
Hydro-micaceous (sericitic), associated with massive diorites 13, 14
Marquette region 3, 31, 38, 39
Menominee region 36, 73
south of Tower, Minnesota 59
of Vermillion range, Minnesota 57-59

Schist, Magnetic 48, 49, 56, 58, 59
Contact of, with diabase 48
Magnetic-actinolitic, of Gogebic region 43, 55, 84
of Marquette region 24, 26, 28, 29, 67, 68, 69, 79, 80
of Menominee region 37
merging with granite 38
Micaceous 78–84
Difference in character of, in Gogebic region and Michigamme district 84
at Ellwood Mine, corresponding to lower strata of Commonwealth Group 83
Garnetiferous 8, 22, 23, 25, 29, 42, 43, 78, 79, 84
of Gogebic region 42, 43
of Gogebic region, identical with actinolite-schist of Michigamme Mine 43
of Marquette region 23, 24, 26, 28, 29, 30, 79, 81
of Menominee region 36, 37, 82, 83
of Penokee region 44
of Penokee-Gogebic region 53
Staurolitiferous 27, 59, 78, 79, 81, 84
Sericitic. See Schist, Hydro-Micaceous.
Schist, Quartz- of Commonwealth group 84
of Marquette region 23, 27, 28
of Menominee region 32, 39, 75
near Tower, Minnesota 59
Scranton Mine 161
S. C. Smith Mine 61, 71
Schoolcraft (Centennial) Mine 117
Sericite. See Hydro-Mica, Etc.
Serpentine in S. 26, T. 39, R. 29 15
Serpentine-like mineral in diabase 111, 118
Siderite 9, 65, 69, 70, 94
Shale, pyritous 75
Silurian 34, 35, 39, 86, 87, 90, 92, 104, 107, 148, 151, 162, 163
Silver 45, 129, 149
Silver Mountain 87
Siskowit Bay 139
"Six Mile" Hill 99
Slate, Arenaceous 61–77
Slate, arenaceous, Mica-schists of Michigamme Lake, in middle horizon of 79
Argillitic 52, 146
Contemporaneous with micaceous schist 81
of Gogebic region 42, 49
Graphitic 45, 46, 52, 56, 62, 64, 66, 69, 71, 73, 78
Graphitic, Thickness of, at Gogebic Lake 45
of Marquette region 64, 65, 66, 70, 81, 84
of Menominee region 74
of Mesaba Heights, Minnesota 60
Micaceous 41, 43, 59, 70
of Ontonagon region 161
of Penokee Gap 56
of Penokee-Gogebic region 10, 50, 54, 55
Slate-quarry 65
"Slide" The 122, 128
Smith, F 117
Soapstone 57
South Copper Range. See South Trap Range.
South Trap Range 20, 49, 87
Southside Mine 102
Spurr Mine 28, 29, 30, 31
Standard Mining Company 23
Stannard's Rock, Amygdaloidal felsite of 86, 140
Star Mine 142
Staurolite 78, 79, 81 84
Steatite, Pseudomorphs of, after feldspar 133
Strike, of Keweenaw series, between Mesaba Heights and Lake Superior 60
of sandstone, S. 28, T. 55, R. 34 103
Sturgeon Falls 15
Sturgeon River 87
Sunday Lake 40, 49, 55, 56
Swede Creek 98, 103
Syenite 6, 132
Tamarack Mine 91, 108
Tamarack Shaft No. 1 111-113, 116
Taylor Mine 61, 62, 65
Tecumseh Mine 111
Terraces of Boulder Drift 40

Thickness of Keweenawan Belts. 91
Thomsonite 141
Thunder Bay 86, 88, 89
Titan-Iron 13, 65, 132
Titanate of Lime (Leucoxene) 13
Torch Lake 104
Tourmaline 30
Tower, Minnesta 59
Town 45, R. 25 71, 72
47, R. 25 9
48, R. 25 4
45, R. 26 71
46, R. 26 71, 72
47, R. 26 4, 14
48, R. 26 4
47, R. 27 22
58, R. 27 110, 139
37, R. 28 16
38, R. 28 15
41, R. 28 34, 35
42, R. 28 8, 33
47, R. 28 14
48, R. 28 21
58, R. 28 136, 138, 139, 140, 142, 157
39, R. 29 15
42, R. 29 33, 34
47, R. 29 70, 81
48, R. 29 67
58, R. 29 130, 134
39, R. 30 16
40, R. 30 14
41, R. 30 36, 37
42, R. 30 37
46, R. 30 22
47, R. 30 22, 23, 25, 26, 27, 28, 79
48, R. 30 67, 80
41, R. 31 36
44, R. 31 38, 39
57, R. 31 123
42, R. 32 84
43, R. 32 75
56, R. 32 117
49, R. 33 62, 64
54, R. 33 92
55, R. 33 101
56, R. 33 110, 112
43, R. 34 76
Town 55, R. 34 98, 103
42, R. 35 14
43, R. 35 77
50, R. 39 146
46, R. 41 19
47, R. 41 20
49, R. 41 153
50, R. 41 153
46, R. 42 19, 41, 42, 84
47, R. 42 44
49, R. 42 152, 153, 154
51, R. 42 161
46, R. 43 42
47, R. 43 9, 19, 44, 45, 46
49, R. 43 152, 154
50, R. 43 155, 156, 157
51, R. 43 158
47, R. 44 19, 40, 46, 55
50, R. 44 157
47, R. 45 40, 47, 48, 49
47, R. 46 10, 40, 49, 50, 51
47, R. 47 10, 40, 52
46, R. 2 E., Wis. 53
62, R. 15, Minn. 58
Trap Mine 151
Tremolite 10, 18, 32, 33
Tungsten 27
Unconformity of Huronian and Keweenawan 87
Union Bay 141, 159, 160, 161, 162
Union Mine 159
Union River 159
Victoria Mine 151
Vein Minerals 121
Vermillion Lake, Minnesota 56, 58, 60, 89
Viridite 13, 65
Vulcan Mine 142
Wadsworth, M. E. 90, 104, 105, 106
Washington Mine 24, 30, 69
Whitney and Wadsworth 2
Whitneyite 94
White Pine Mine 161
Windsor Mine 151
Winslow Mine 23
Wolverine Mine 117
Wood, Mr. 52
Wright, J. N. 114

PART II.

THE GEOLOGY
OF
LOWER MICHIGAN
WITH REFERENCE TO
DEEP BORINGS

EDITED FROM NOTES OF

C. E. WRIGHT, LATE STATE GEOLOGIST

BY

ALFRED C. LANE, ASSISTANT STATE GEOLOGIST

WITH AN INTRODUCTION ON THE

ORIGIN OF SALT, GYPSUM AND PETROLEUM

BY

LUCIUS L. HUBBARD

AND ACCOMPANIED BY SEVENTY-THREE PLATES AND A MAP

OFFICE OF THE STATE GEOLOGICAL SURVEY,
Houghton, Michigan, August 28, 1893.

To the Honorable,
The Board of Geological Survey of Michigan:

GENTLEMEN—In accordance with your request, I have the honor to transmit herewith a paper, prepared during the administration of my immediate predecessor, by Dr. Alfred C. Lane, on the Geology of Lower Michigan, with Reference to Deep Borings.

With great respect, I am your obedient servant,

LUCIUS L. HUBBARD,
State Geologist.

TABLE OF CONTENTS.

INTRODUCTION.

The origin of salt, gypsum and petroleum.

CHAPTER I.

GENERAL CONSIDERATIONS.

§ 1. Value of geological study of lower Michigan.

§ 2. Difficulties in the way of the investigator, and importance of the knowledge gained from borings.

§ 3. Errors in the records of borings:
(*a*) Inexact location;
(*b*) Inexact altitude of well-head;
(*c*) Inexact measurement of depth;
(*d*) Inexact description of samples;
(*e*) Intermixture of samples.

§ 4. Method followed in this report.

§ 5. Relative value of paleontological and of lithological divisions of rock series.

Historical review; neither classification of universal value; both legitimate within certain provinces; the lower peninsula of Michigan mainly one province in both senses; transition periods; minor lithological variations independent of general development; divisions used in this report, both lithological and stratigraphical.

Chapter II.

THE GEOLOGICAL FORMATIONS OF THE LOWER PENINSULA AND THEIR ECONOMIC PRODUCTS.

§ 1. Detailed description of the different formations:
- (*a*) Quaternary;
- (*b*) Jackson Coal Group:
- (*c*) Grand Rapids Group;
- (*d*) Marshall Sandstone;
- (*e*) Coldwater Shales;
- (*f*) Richmondville Sandstone;
- (*g*) St. Clair Shales;
- (*h*) Traverse Group;
- (*i*) Dundee Limestone;
- (*j*) Monroe Beds;
- (*k*) Niagara and Clinton;
- (*l*) Medina Shale;
- (*m*) Hudson River Shale;
- (*n*) Utica Shale;
- (*o*) Trenton Limestone.

§ 2. Occurrence of economic products:
- (*a*) Coal;
- (*b*) Plaster;
- (*c*) Mineral waters;
- (*d*) Salt brines;
- (*e*) Bromine and other possible products of bitterns;
- (*f*) Oil;
- (*g*) Gas.

§ 3. Methods of testing samples from borings:
- (*a*) Apparatus needed for tests;
- (*b*) Substances to be recognized;
- (*c*) Methods of investigation.

Chapter III.

LOCAL DESCRIPTIONS.

§ 1. (*a*) Description of well-sections and of the method of their preparation;
(*b*) Description of the map of the Lower Peninsula;
(*c*) Description of the geological sections;
(*d*) Directions for their use in ascertaining what rocks may be expected under a given place.

§ 2. Particular descriptions of deep borings, arranged alphabetically.

General Index.
Index to Records of Borings.
Explanation of Plates and Map.

ERRATA.

Part II.

Pages 26 and 35, 3d and 15th lines, respectively, for "Petrolea" read "Petrolia."

Page 26, 11th line, for "Mason" read "Macon."

" 61, 6th line, for "R. R." read "R'w'y."

" 69, 12th line, for "900" read "400."

" 69, 23d line, for "H. W. Daw" read "H. H. Dow."

" 71, for "Newberg," wherever it occurs, read "Newburg."

" 71, 7th and 8th lines, "203" and "305" refer to wells Nos. 1 and 2 respectively.

" 71, 17th line, for "1130–1200" read "1180–1280."

" 78, 7th line from bottom, for "dips" read "depths."

" 79, between 9th and 10th lines, insert, as first group in Hamilton, "230–250, Limestone."

The cross-references from one well-record to another, giving equivalent depths, are meant for guides only, and the reader must not depend on them for minute accuracy, which is in fact often impossible to attain. There are some minor inaccuracies which are not here noted, because they are less than the probable error inherent in the record, e. g., on Plate II, the reference "L. R., 1300" should perhaps more precisely be "L. R., 1293."

INTRODUCTION.

THE ORIGIN OF SALT, GYPSUM AND PETROLEUM.

The material from which were derived, in great part, the data used in the preparation of this paper, was gathered by Charles E. Wright, deceased, late State Geologist, and consisted of a large number of samples from borings; of about sixty diagrams of salt wells, mainly complete; and of Mr. Wright's note books.

To these data Dr. Lane has added a few records, and has prepared six new sections, a map, and other illustrative matter. It is due both to the reader and to Dr. Lane to say that the latter is not personally familiar with the surface geology of the lower peninsula of Michigan. This paper, the credit for whose preparation belongs to the administration of my predecessor, Dr. M. E. Wadsworth, embodies what few facts the Geological Survey possesses on the deep borings of Michigan. No geological report on a subject of this kind can be expected to be final, and although the facts may be meagre, it has been thought wiser to lay them before the people and to try to point out their significance, in the hope that by so doing we shall furnish an incentive to further researches, as well as, to a certain extent, a guide to their successful prosecution.

These facts have been gathered from many sources during the search for deposits of salt, gypsum, oil, and other useful products. Before proceeding to their consideration, however, it may be worth while to give a resumé of the principal theories that have been advanced to explain the origin of the vast deposits of salt and gypsum that occur in different parts of the world, and of petroleum, which is often found in more or less intimate association with salt in one form or another. This resumé aims to give a simple account of the supposed processes of Nature. We shall see that the same facts may lead to conclusions that in some respects

are diametrically opposite. It would be foreign to our purpose, nor would space and time permit us, to attempt to discuss at any length the different theories, or to weigh critically their relative merits, even if we were disposed to do so. The incompleteness of human knowledge makes progress toward the goal of truth very slow, and what may seem plausible today, may to-morrow, in the light of new evidence seem improbable, or even absurd. The duty of the investigator is to record observed facts and to wait patiently until enough of them are gathered to explain the phenomena about him. This is at least safer than to theorize on insufficient data. When the geologist can account rationally for the cause and method of deposition of substances that are of economic value, he may be able to predict where deposits of similar substances are likely to be found.

The primitive ocean of our globe is considered by some writers to have been as pure as rain water, by others to have been salty. Indeed, Schleiden says the ocean was originally a saturated brine with 33 % of salts. The water of the ocean at present contains in solution about 3.6 % of solid matter (2.5 % salt). As pointed out by Ochsenius,* if we allow the ocean an average depth of 3,600 meters, to restore it to a condition of saturation (25 % salt) would require a crust of salt 300 meters thick for the entire surface of the earth. G. Bischoff thought that the ocean was a million years in attaining its present degree of saltiness, and that it was the ancient, or crystalline rocks that were the principal source of the different salts that now make up this percentage. According to another writer, salt originated in animals and organic growths; according to a third, it was originally distributed over the earth in the form of rain as a saturated brine, which, beside enriching the ocean water, permeated many of the rock formations. That smaller quantities were brought by winds in moisture from the ocean and precipitated on the land is a much more common and a better grounded belief. By some, a salt-creating force in the atmosphere was supposed to produce superficial deposits of salt—certainly not a very scientific theory, if we are to understand by it that something came out of nothing. A deluge of brine in the early stages of the earth's history would have made the early formations salty to a greater degree than we commonly find them, and, unless speedily

* Chem. Zeitung 1887. 11. No. 56 et seq.

carried off, or diluted by fresh water, would have been likely to prevent the development of organic life. Salt, it is true, occurs in formations as old as the Silurian, but nowhere in beds of enormous thickness until we come down to Permian times. The vaster deposits of salt appear in the Trias and from there up to the Tertiary, and salt beds are in process of formation even at the present day. Different topographic conditions must have prevailed in different stages of the earth's development. Agassiz says that the types of mollusks from the Devonian to the Cretaceous belong almost exclusively to the ocean. Fresh water fauna are subordinate until we pass into the Cretaceous. By this time with the growth of sedimentary deposits and of volcanic flows, the crumpling of the earth's crust, and the re-arrangement of rock material, there were more basins inland for the accumulation of fresh water and others on the border of the ocean that may have been filled with salt water, or alternately with fresh water and with salt water.

We see from the foregoing that, however and from whatever source salt may originally have been derived, the ocean has been one of its great repositories since the time when the sedimentary deposits began to be laid down, and while some of the theories already quoted may account for small or sporadic deposits of salt in the older Paleozoic formations, no one of them accounts satisfactorily for deposits of such magnitude as, for example, that of Stassfurt, Germany, where the salt formation has been bored into vertically to a thickness of 325 meters without reaching its foot-wall, or of Sperenberg where, although less pure than at Stassfurt, the salt has been found to be 1,194 meters thick. The ocean alone gives us a safe starting point as a source of the salt deposits of more recent geological ages.

The principal associates of salt in its solid form are gypsum and anhydrite, the hydrous and anhydrous sulphates of lime; dolomite, the carbonate of lime and magnesia; the more soluble potash salts; as well as sulphur and petroleum. When we come to consider the two principal theories that have been advanced to account for the great salt deposits and their associated rocks, it may be well to bear in mind that in sea water we find the same elements that enter into the composition of the above bodies. From sea water we can obtain rock salt (chloride of sodium, NaCl), the very soluble potash salts (KCl, etc.), lime-

stone (carbonate of lime, $CaCo_3$), gypsum and anhydrite (the hydrous and anhydrous sulphates of lime, $CaSo_4$ ($+2aq$)), sulphate and chloride of magnesia ($MgSo_4$, $MgCl_2$), together with bromine, iodine, double salts of some of the foregoing, and organic substances. In the laboratory we can get only a mechanical mixture of $CaCo_3$ and $MgCo_3$, but never a chemical mixture of the two that corresponds to dolomite $(Ca, Mg)CO_3$.

The two theories just referred to are the *volcanic* and the *aqueous*. According to the one, dolomite, salt and gypsum were brought up from the inner parts of the earth, either (1) as molten masses, accompanied by great heat and the development of gases, and with or without a display of violence, just like our basalts, porphyries and other volcanic rocks; or (2), they formed by the action of gases, either by sublimation or by the alteration of bodies already in place, or (3), they formed in concentrated solution in hollows down in the earth's crust, and either solidified there after the manner of granite, or were exuded to the surface through cracks and fissures, after the manner of porphyries; or (4), they (gypsum and salt) were ejected with violence in the form of slime, a phenomenon familiar to us in mud volcanoes.

The agency of gas in these deposits—its action on rocks previously existing—was a favorite theory. Hydrogen sulphide (H_2S), or fumes charged with sulphur acted directly on limestone, or they decomposed water, forming sulphuric acid gas (hydrous or anhydrous); the latter drove out the carbon dioxide (CO_2) in limestone and formed gypsum or anhydrite. Salt was formed by the action of NaCl gas, and dolomite by that of $MgCo_3$ gas; these gases were concomitants of "black porphyry," the intrusion of which followed fissures by which they gained access to the different rock strata above their place of origin.

The thick lenticular masses of dolomite and gypsum often met with are the masses to which the theory of a sub-surface formation was particularly applied. Hollow places below the surface of the earth become filled with liquids, heated and concentrated to the consistency of a paste. Sulphur fumes entering caused the chemical changes above pointed out, and the formation of gypsum which often remained of the consistency of a paste. Salt separated out of the paste, and according to the amount of impurity with it, formed rock salt or salt clay. The various

mixtures were often ejected with violence, but as insufficient heat was developed to melt, this phenomenon is more closely allied to that of explosion- or mud-volcanoes.

The broad theory that salt deposits are formed by precipitation from sea water in basins connected with the ocean, was advanced as long ago as the last century, but not until recent years has it been taken up in detail, by Dr. C. Ochsenius,* who by means of some important modifications seems to have reconciled several weighty objections formerly urged against it, and to have made out a strong case in its behalf. This theory is particularly applicable to deposits like that of Stassfurt.

The evaporation of sea water in the laboratory precipitated, according to Usiglio, first (Sp. G. 1.0506, 1.1304), small quantities of carbonate of lime ($CaCO_3$) and of hydrous oxide of iron; then 83.82 % of all its sulphate of lime ($CaSO_4$) (Sp. G. 1.13 1.22); then 54.17 % of all its rock salt ($NaCl$) at the same time that 16.18 %,† the balance of its $CaSo_4$ was being precipitated; then 8.5 % of its salt ($NaCl$) without any admixture of $CaSO_4$. The remainder of its $NaCl$, together with the more soluble salts of magnesia, potash, bromine, and iodine, which compose the bitterns, finally crystallized in various combinations.

If the same process takes place in nature, undisturbed by local influences, such as inflowing rivers and rainfall, we can imagine a basin of sea water shut off temporarily by some catastrophe from connection with the ocean, its water evaporating under the influence of tropical heat. This will correspond to what is called a "salt-garden." The bottoms and sides of the basin will be coated with carbonate of lime, more or less colored by iron, on which will be a layer of sulphate of lime, gypsum. The concentrated brine retreating to the lower parts of the basin, salt will soon begin to precipitate with the gypsum until the latter is all thrown down, and the final or upper salt strata will be approximately pure. The bitterns retreating to the hollows of the basin, their very soluble salts will be the last to crystallize, in part as a thin skim on the sides of the basin, and if the basin receives a slight access of water from inflow or atmospheric moisture they

---

* See Die Bildung der Steinsalzlager und ihrer Mutterlaugensalze. Halle, 1877; Nova Acta der Ksl. Leop.—Carol. d. Akad. der Naturforscher. Bd. XL, No. 4; and Chem. Zeit., 1887, 11. No. 56, which also contain references not cited here.

† The total $NaCl$ being to the total $CaSO_4 = 27.11 : 1.75$, this amount is relatively small. Almost all analyses of rock salt show at least traces of $CaSO_4$.

will quickly redissolve, perhaps with a small portion of salt, and may or may not eventually be removed. The alternation of winter and summer, or even of night and day, might have the same effect, and the bitterns would then seek the lowest parts of the basin, where they might recrystallize in a more contracted space. Animal life in the basin when the barrier formed between the latter and the ocean, would soon be unable to exist in the concentrated waters. Vegetable matter in the water would be imbedded with the deposits as they formed, its position depending, of course, upon its specific gravity relatively to that of the concentrating waters. The desert of Sahara and the eastern coast of the Red Sea furnish good examples of the processes described above.

In a case of this kind the amount of solid salts cannot, of course, exceed the amount of salts in solution in the basin at the time its barrier formed, supposing it receives in the mean time no salts from other sources. This amount is only 1-60 of the cubic contents of the basin. We can, of course, imagine a disruption of the barrier, or the irruption of the sea at regular intervals. The new supplies of sea water thus introduced into the basin might on evaporation give us a repetition of the first deposits, but not an immense uninterrupted deposit of any one substance. Deposits like that of Stassfurt can therefore not be accounted for, says Ochsenius, by supposing them to have formed in a closed basin. We must presuppose a basin of sufficient depth, an *almost horizontal channel connecting it with the ocean*, and the ability to evaporate the inflowing water as rapidly as it is received.

The continuous connection of the basin with the ocean is the principal point in the argument for the formation of the very thick deposits of salt, but is not necessary in order to explain all salt deposits.

Under the above named conditions, the upper layers of water in the basin become heavier, as evaporation proceeds, and sink. They come in contact with layers differently charged. Chemical changes take place, which result finally in the deposition of various salts, principally of sulphate of lime and chloride of sodium, according to the varying specific gravity of the solution, as already noted, and to other factors that will be mentioned subsequently; while in solution, the chloride of sodium (rock

salt) will tend to lie in the lower strata, and the magnesia salts between these and the surface. As the water concentrates, the fish will seek the highest and freshest parts of the basin, and will finally pass out of it. We find comparatively few remains of fish in great salt beds. In the Caspian Sea, which has no outlet, and in a great basin of which, the Adschi-Darja, salt is continually forming, fewer fish are found in those parts that are richer in magnesia salts than are found in the highest, less salty layers, and fewer fish in the Adschi-Darja than in other parts of the Caspian Sea.

The bottom of the Straits of Gibraltar forms an imperfect bar between the Atlantic Ocean and the Mediterranean Sea. An under-current flows out of the latter into the former, while a current from the Atlantic flows in at the surface. The water of the Mediterranean contains in proportion to its salt ($NaCl$) $2\frac{1}{2}$ times as much sulphate of magnesia ($MgSO_4$) as the water of the Atlantic, and the excess of this $MgSO_4$ is supposed to lie in the higher layers, between the surface layers and the level of the top of the bar. The water below the bar is relatively stagnant and of a relatively uniform temperature and chemical composition. The temperature of the water under those layers that are affected by the sun is equal to the mean of the winter temperature of the Mediterranean Sea at the surface, 12.8°. It follows, therefore, that none of the upper layers on concentration can attain a density that will enable them to penetrate below the level of the bar. They will therefore, as it were, glide over the lower zone, and giving way to the "feed water" from the Atlantic, will pass out under it into the latter body. It is a similar action that Ochsenius applies to the salt basins.

The layers of water that are rich in magnesia salts set up a counter-current and flow out of the basin under the incoming current of sea water. Thus there are constantly introduced fresh supplies of gypsum, salt, etc., while the more soluble salts are being carried away. It is evident that upon the rapidity of evaporation and the consequent varying specific gravity of the water will depend the salts, in kind and amount, that are precipitated in the basin. If the inflow and distribution over the basin were constant and uniform for long periods, and the specific gravity were maintained steadily between 1.0506 and 1.1304 we should have a deposit of nearly pure limestone. With the

specific gravity between 1.1304 and 1.22, we should have sulphate of lime (gypsum), and beyond the latter point salt would form rapidly. Under favorable conditions this process might continue until the basin was filled with precipitates, or until the barrier was closed, when the salts of the bitterns would be precipitated and lastly the anhydrite cap would form over them all. The magnesian and potash salts, owing to their easy solubility, might be carried off later in solution.

The occurrence of absolutely pure rock salt is therefore possible only after fresh accessions of sea water are rendered impossible, *i. e.*, after all the gypsum is deposited. A recurrence of pure salt in different strata would point to the periodical closing of the bar.

Salt and gypsum deposits are frequently impure from the presence of sand and clay. Both of these substances might be brought in from the sea, or the latter might come largely from the surrounding lands, being brought by the winds and scattered uniformly over the whole basin. In the last stages of desiccation, the basin would be a "bitter lake," and under its influence the shores would be likely to become barren of vegetation and be without protection from the erosive force of the wind. Hence we should expect to find layers of clay or of sandstone over salt deposits, some of them perhaps saturated with the more soluble potash salts.

The *annual rings* at Stassfurt, to which reference is made on page 9 of the following text, are by Ochsenius ascribed to local causes. According to Usiglio, sea water concentrated to one-half of its volume (*i. e.*, specific gravity = 1.0506) deposits a large part of its $CaCO_3$, but between this point and a further concentration to 19 % of its original volume only traces of $CaCO_3$ fall down. At the latter point, however (specific gravity = 1.1304), another large precipitation of $CaCO_3$ takes place ($\frac{33}{64}$ of first precipitation). The first precipitation begins gradually and ends abruptly, the second begins abruptly and ends gradually. This is supposed to be due to the mutual decomposition of $NaCO_3$ and $CaSO_4$ and the formation of Na_2SO_4 and $CaCO_3$. Therefore if there be any substance in the solution, that falls down when the specific gravity of the liquid varies between 1.0506 and 1.1304, it will lie between two layers of $CaCO_3$, against which it will be quite sharply delimited. Ochsenius thinks that from the known greater

solubility of gypsum in salt water than in fresh, and from the probable formation, on concentration of the sea water, of double salts, or perhaps of the four salts, $NaCl$, $CaCl_2$, $NaSO_4$ and $CaSO_4$, sudden and well marked deposits of $CaSO_4$ might be caused by a sudden dilution of the concentrated water, or by the addition to it of Na_2SO_4 or $CaCl_2$. So also $CaSO_4$ is insoluble in a saturated solution of $MgSO_4$. The outflowing magnesian and other salts with the incoming sea water might produce these salts or others like them, and the return to the basin of the resulting salts might be caused by certain periodic winds. Hence the direction of the mouth of the basin with reference to these winds would be the principal local factor. The fact that only one other locality, near Dieuze, shows annual rings, while others near Stassfurt do not show them, is an argument against the theory that these rings of anhydrite are due solely to a change from a summer to a winter climate, for in the latter case they should be more general, in the same locality at least. These periodic winds, however, may be due to a recurrence of seasons.

The presence of anhydrite in connection with salt deposits, where gypsum might be expected, especially as a cap to the principal salt deposit, has been explained by Ochsenius as due to the fact that the hydrous sulphate of lime in solution with some potash salts exchanges part of its water for sulphate of potash, in the formation of polyhalite and other salts, and this exchange results in the formation of the anhydrous sulphate, anhydrite ($CaSO_4$). Dr. Lane has observed that many occurrences in Michigan borings, generally taken for gypsum, are in reality anhydrite. Unless this form of the sulphate occurs with other salts in a solid state, it is of course impossible to verify or disprove the accuracy of the above explanation.

A glance at a geological map of Michigan and neighboring territory will show a series of sedimentary formations, one of the lowest of which, the Huronian, rests on the northwest, north and northeast on Laurentian rocks, forming a great basin. The different formations from the Huronian, or more strikingly from the Cambrian (Potsdam sandstone) up to the Coal Measures (Jackson Coal Group) outcrop around the edges of this basin, dipping gently toward a point, which for the later of the formations is the center of the basin, which lies near the middle of the lower penin-

sula. These formations, consisting of limestone, dolomite, sandstone, and rocks nearly related to these, form approximately concentric shells that were laid down in past geologic times, the lowest of them, up to and including the Monroe beds (Upper Silurian) as parts of a wide basin that extended from Wisconsin to the east, as far as the Appalachian mountains in New York, and south into Ohio, where it connected with the ocean which then covered the lower Mississippi valley. From the Monroe beds and up to and including the Coldwater shales the basin seems to have been more intimately connected with western Ohio and Indiana. The east side of the Michigan basin shows signs of having been elevated at the time the Berea was forming. This lies just below the Coldwater. Beginning with the Grand Rapids group, the great gypsum-bearing horizon, the basin seems to have contracted still more, to have shifted its center westerly, and to have been confined more nearly within the present land limits of the lower peninsula of Michigan. To explain the presence in the Michigan strata of deposits of gypsum, of rock salt and of other salts commonly associated with the latter, we are justified in assuming conditions that correspond with the more probable of the two theories above considered, that of an aqueous origin. In fact the "eruptive theory" has long since been pretty generally discarded. The records show deposits (30 to more than 100 feet thick) of rock salt in or below the Monroe beds, which probably correspond with the salt-bearing strata of western New York. Below these salt beds there should be expected a very general deposit of gypsum. In the southwestern part of Michigan, and in Ohio, this gypsum has been found, but as yet no salt has been found with it, so far as we know. The latter thinned out towards the edge of the basin and may also have suffered some erosion. The salt beds under Monroe county appear to be underlain by limestone. To account for the deposit of the salt of Michigan, in all four of the salt horizons, the assumption of an uninterrupted connection of this basin with the sea, for a long period of time, does not seem, so far as the evidence goes, to be required. Indeed the intervening formations between the different horizons, and the relatively small amount of the salt deposits point to the repeated interruption of this connection and to changes in the earlier conditions, among which the contraction and disturbance of the basin by epeirogenic

or continental movements were not the least important. Our chief concern is to ascertain, if possible, what parts of the basin were deepest during the deposition of the gypsum in the Grand Rapids epoch. In those deep parts we might expect to find equally thick deposits of gypsum throughout the basin. In like manner we might confidently look for the deposits of rock salt around the basin, that occur in the Monroe beds at Wyandotte, Royal Oak, and along the St. Clair River, at least if we knew where to locate the deeper parts of the basin as it existed during the epoch of the Monroe beds. The cross-sections accompanying this report are meant to be of aid in this connection. With additional information derived from the boring of new wells, we may expect in time to be better able to define the various flexures and irregularities of our rock strata, so that deposits of the more insoluble salts can be located with greater precision. Folds in the formation and subterranean percolation would be likely to disturb the original position of the deposits of the more soluble salts, whose present position would then depend in a measure on their specific gravity, on hydrostatic pressure and on factors of a complicated nature.

Petroleum, a mixture of hydrocarbon compounds in varieties of different appearance and chemical composition occurs, in a state of nature, in small quantities on the surface of the earth, and in different formations from the Silurian up to the Tertiary.

It occurs often in regions where salt deposits are found and, with gas, not infrequently comes up with the brines of salt wells, sometimes preceding and sometimes following the brine. It is most frequently found in sandstones or other porous rocks, where it may occupy a space equal to one-tenth of the bulk of the rock. It collects usually under an anticlinal, *i. e.*, under strata that are wavy, or slope downward from a crest in two opposite directions, where, if it lies between two impervious strata it is kept together in the same zone until released by an opening, natural or artificial, in the strata that cap it.

In Pennsylvania the oil belt is fifteen to twenty miles wide, and extends from southern New York to northern Tennessee, in gently undulating strata of the Hamilton and Chemung, along the edge of the Allegheny mountains parallel with and fifty miles west of the latter. The productive parts appear to have no connection

with one another, although they probably belong to the same geological period. Miles of unproductive territory lie between the rich intervals. The coal and oil of Pennsylvania are widely separated in depth, the coal being above the oil. In the Caspian district the oil deposits lie in Cretaceous strata that extend on each side of the Caucasus mountains and along their prolongation southeastwards beyond the Caspian Sea. In Galicia, petroleum products are found in Tertiary strata along the line of the Carpathians; in South America and in California on the western mountain slope next to the Pacific Ocean. In the latter case the oil is in Tertiary strata which, unlike the Pennsylvania oil-bearing strata, are highly tilted.

In Pennsylvania and in Ontario the oil occurs principally in the Hamilton group of the Devonian age and in the Corniferous just below it. In Michigan what may be taken approximately as the equivalent in age of the former of these groups embraces the St. Clair shales and the Traverse below them, which have thus far not shown oil and gas in paying quantities, although traces of these substances are frequent in each of them. The Dundee in Michigan, the probable equivalent of the Corniferous, has also shown more or less gas and oil.

So far as we are informed, no drill hole in Lower Michigan has yet pierced the Trenton, the oil horizon of Ohio and Indiana, except at or near Monroe, where some gas was observed.

The beds in which the great deposits of oil are now found are most of them supposed not to be the place of origin of the oil. The uncertainty as to which are the mother beds deprives us of positive evidence that might go far towards a satisfactory explanation of the origin of oil, and geologists and chemists, especially the latter, are forced to offer their theories in a tentative way rather than as conclusions that can be accepted as final.

A theory that once found favor was that petroleum was a product of distillation derived from vegetable substance during the formation of anthracite. Again, it was thought to be the product of dry distillation of vegetable matter with bituminous schists. These views have been pretty generally abandoned, so far, at least, as the vaster deposits of oil are concerned, because petroleum is rarely if ever found in coal beds or near them, unless animal remains are also present. Oil occurs in beds of marine origin, where comparatively few plant remains are found. In

these beds, on the contrary, are often found many remains of animal matter, and in close connection with them salt solutions of various composition. The water of the coal deposits, on the other hand belongs to the class of hard waters, and cannot as a rule be called salty.

Some investigators have thought that petroleum was the product of water vapor, carbon dioxide, and sulphuric acid or hydrogen sulphide, acting on iron. This theory seems to be based purely on the facts that these substances occur in the earth's interior, and that an oil resembling petroleum can be artificially produced by their combined action. Similarly, carbon dioxide acting on alkali metals forms acetylides, these, in turn, with hydrogen form acetylenes, from which petroleum might result.

Mendelejeff rejected the organic theory; because petroleum is often found near the surface of the earth, having been brought there by circulating water, than which it is lighter; because it is found chiefly in sandstones and other porous rocks where there are no carbonized organic remains; because it is found in nearly straight lines or arcs of great circles rather than scattered irregularly through different strata, as would be the case if it had formed in place. Therefore, he says, it must have been formed in some lower strata. These reasons, it may be pointed out, do not conflict with the organic theory and are in fact generally accepted by advocates of the latter. That the vaster bodies of oil are found in strata so low in the geological horizon, as for example, in the Hamilton in Pennsylvania, that sufficient organic remains for their production cannot be expected to have existed in strata below them, is an objection of weight, but for a reason already stated is not conclusive. Mendelejeff assumes an accumulation of metals in the earth's interior, especially of iron, as well as of carbon compounds of the metals. Water penetrates to the latter, and under pressure and a high temperature acts on them, forming metal oxides and hydrocarbons. These rise in the form of vapors, are condensed in the colder strata to oil, which collects wherever it finds a suitable receptacle. It has been objected against this theory that, if oil formed at such great depths in the earth, we should find more evidences of its occurrence in volcanic rocks and in those rocks of the earth's crust that lie nearest the supposed seat of generation of the oil. Besides, as already stated, we know that remains of animal matter do occur in petroleum

beds, and we may safely infer that not all petroleum deposits are necessarily removed from their place of origin.

The distillation of train oil produces nearly all the compounds of petroleum and a gas that contains much marsh gas (CH_4). A dry distillation of muscles and sea-fish shows a large amount of ammonia and of nitrogenous organic bases, from which it appears that the flesh of animal bodies is nitrogen-bearing, while the fat is nitrogen-free. The former is subject to rapid decomposition, and in the earth's strata its constituents may to a great extent be carried off by percolating waters, while the fat remains as a source of petroleum.

Ochsenius* cites the decomposing action on one another of marine sulphates in contact with organic detritus and the formation of sulphur therefrom; the occurrence of bromine and iodine in the residue of petroleum distillation; of sulphide of ammonia and carbon dioxide as products of the distillation of crude petroleum; in several oil regions, of tungsten which is supposed to be an ear-mark of mother liquors or bitterns; of hydrogen sulphide, and of sulphur in petroleum; and lastly of salt and other chlorides in petroleum water, and concludes that it is the mother liquors from salt basins, that have not only caused the death, in large masses, of marine animals, but have also been the principal factor in their conversion to petroleum.

Therefore the occurrence together of gypsum, salt, petroleum and sulphur suggests to Ochsenius the probability that the two former mark the birthplace of mother liquors, which on the one hand form petroleum from animal remains, and on the other furnish the material for sulphur deposits. The mother liquors here play the part of the great heat required for the artificial production of petroleum. He mentions a locality in Alsace described by A. Andreæ, where sandstone strata were found saturated with oil; salt water beneath them and marsh-gas above. The strata were brackish and contained fossils, snails and plants. In the higher strata were abundant foraminifera. The deposit of oil was surrounded by a zone rich in brown coal, and the sandstones bore impressions of the leaves of land plants. This occurrence, which Ochsenius considers as corroborative evidence of the correctness of his theory, does not seem to exclude vegetable remains from being at least co-agents in the production of petroleum, nor does

*Chemiker-Zeitung, 1891, 15, No. 53.

it satisfactorily prove that a mother liquor with its magnesia salts must be the chief agent in this process.

Whatever be the materials from which and the process by which petroleum is formed, we know that oil deposits occur very generally along some old shore line of a former ocean in intimate connection with sea water, in contrast with coal deposits, which, essentially a product of land or fresh water vegetation, are seldom found in intimate association with petroleum; that they occur in distinct and independent deposits for some distance throughout approximately the same stratigraphic zone, interrupted by unproductive intervals; that these scattered deposits may represent so many bays or basins which once formed receptacles for the deposition of salts from the water of the ocean from which they were fed; that the barren parts of these oil zones represent, either land that separated the bays from one another, basins that were not suited for the deposition of salt, or points that were stratigraphically unfit for the retention of oil. This is at once much more apparent in the cases above cited than in more inland localities, where the topography is flat, as in Ohio, for example, which however at one time was under the waters of a shallow bay connected with the ocean on the south. After the deposition of salt and, in some cases, of mechanical detritus above it, owing to the presence of salts of magnesia (mother liquors) or to some other cause, petroleum was formed by a process of slow distillation from organic remains, probably both vegetable and animal. Naturally seeking a higher level, either in the form of gas or of liquid according to the temperature of the surrounding rocks, to the pressure to which it was subjected, and to the circulation of currents of water near it, the petroleum lodged where it found porous rocks with an impervious dome-shaped or corrugated cap—an anticlinal reservoir—and a more or less compact stratum below it. If the impervious overlying stratum was tilted, the oil probably kept on its course upwards until it reached the outcrop of those strata. Where this outcrop was buried under hardpan or glacial drift, the oil might again be confined. Where the strata of the cap are broken or disturbed, the oil escapes upward and may finally be dissipated. That no oil belt is found on the east side of the Allegheny mountains is ascribed to this cause. That all deposits of petroleum in its different varieties were formed in the same way is not probable, nor is it impossible that some bitumi-

nous products may be of vegetable origin. When the oil is associated with gas and salt water, we naturally find the gas at the top and the water at the bottom, although the order of exit of these products from a hole penetrating their vicinity must depend upon the local structure and the relative position of the hole to the different substances in confinement.

LUCIUS L. HUBBARD.

CHAPTER I.

GENERAL CONSIDERATIONS.

§ 1. The Geology of Lower Michigan is well worthy of careful study from a practical as well as from a theoretical standpoint. For underneath its fields and forests are buried treasures of coal, salt and plaster, which are known to be of great value, and it is more than likely that greater quantities of these, and of building stone, lime, cement, marbles, gas and oil still await development. But while this is true, the surface of the country is so covered with gravels left by the great ice age, and is so gentle in its relief, that outcrops of rock are very scarce, and it is only by a careful comparison of facts that we can form a true idea of the structure beneath our feet.

§ 2. The mode of arrangement of the rocks is fortunately very simple, and was long ago made out by Bela Hubbard,* and has been since more carefully studied and explained by Alexander Winchell and after him by Carl Rominger. I say fortunately, for were it otherwise the geologist's lot had indeed been hard, as there are serious difficulties in the way of the investigator. Some of them have just been mentioned, and others, which have only gradually been realized, are the change in character, and the great increase in thickness of the rock beds, in passing from south to north.

Successive reports show a steady increase in the estimates of the thickness ascribed to the beds of rock lying between the Trenton and the Coal Measures, so that while the geological column (Plate LXXIII) shows almost the *minimum* thickness of the beds in the state, the thickness thus given is quite as great as that given by any previous writers.

* 4th Rep. State Geologist, Sen. Doc. No. 16. 1841. p. 137.
See A. Winchell, Proc. A. A. A. S., 1875, Pt. 11, p. 27.

For the causes of this misapprehension of the thickness, we have not far to seek. The states south of us, Ohio and Indiana, which, according to the law just mentioned, have much thinner beds than the corresponding formations in Michigan, were earlier and more carefully studied by geologists, in spite of the fact that our mineral resources are more varied than theirs. The published results of geological work done in these states are, at least, more complete than ours; the Michigan State Survey has been twice interrupted, and thus much material has been lost or buried.

The geologist has therefore always been tempted to use the records of the aforesaid states as standards of comparison. Moreover, the lower part of the rock series, if we may judge by the exposures in the Upper Peninsula, does not seem from all accounts to be very thick. Yet we are undoubtedly nearing old shore lines in moving north, and for a part of the time Michigan belonged geologically, as we shall see, rather with Ontario and New York than with the states south of it.

Under these circumstances it is easy to imagine how much light may be given by the records of deep borings and how eagerly it would be welcomed by the geologist.

§ 3. Before we go on to describe these records and the results we obtain from them, it behooves us to consider to what errors they are liable, that we may know how far we can depend upon our deductions from them.

A perfect well-record would show us exactly what kinds of rock there were below a definite point at all depths.

We do not find the same kind of rock at the same depth in different wells for some of the following reasons: (1) Because, while the rocks remain the same and unaltered, and are horizontal, the points from which we bore are not at the same altitude, or (2) because the bed, though it remains horizontal, has changed its character, having, for example, become more sandy, or (3) because the beds themselves have a dip, which may be due to a tilting or folding of the rock series as a whole, or merely to the thickening and thinning of one or more beds lying between the bed under consideration and the surface. Any lack of information which hinders our judgment, or any misinformation which causes us to misjudge as to the matters aforesaid, tends to spoil or render inaccurate our work.

Among the points, at which many records fail, are the following:

(*a*) First, the point at which the well is sunk is often not exactly known. "At such a town" or "near such a town" leaves a probable range for the location, of a couple of miles each way and a possible range of much more. Even location by streets, while of course more exact, is not satisfactory, because local maps or authorities must be referred to before the true place on the state map can be determined. Much the better way is to refer to the section, township and range of the original land survey. If we know in which "forty," or quarter of a quarter section the point lies, that is often at present as near as we can get. But decidedly the best method of reference is to the southeast corner of the section, with the statement as to how many feet, steps or paces (2,000 paces = one mile) north and west of that location the boring is. Of course to determine that, it is necessary only to walk to the nearest point whose position in the section is definitely known.

The nearer the wells are to each other, the more important it is to have their exact location given, that the full benefit of their records may be obtained. For if we can have the exact locations, altitudes and depths of three adjacent wells, we can thence derive the dip of the beds in the neighborhood and find the rate of rise and fall of the beds in any direction.*

(*b*) Secondly, the exact altitude of the well-head, *i. e.*, of the point from which the measurements are taken, *is not known for a single one* of the records transmitted to me from Mr. Wright. Yet, obviously, if we wish to get the dip of a bed, it is necessary that its depths at different points be referred to a datum plane, and the altitude of the well-head nearly enough for practical purposes can be obtained by a hand-level or even by a barometer.

Borings are not often made far from railroads or other means

* See Green's Physical Geology, p. 463, whence we take the following easy graphical construction:

Let A, B and C be the position on a map, of three wells that cut a certain bed, A being the well in which the bed is deepest, and the elevation of the bed in all the wells being referred to a common level, *i. e.*, to tide level. Lay off along the direction AB a measured distance AZ. Along AC lay off AY, so that AZ:AY as the difference in depth above or below tide level, of the same bed respectively in A and B, and A and C. Then Z and Y should be vertically over points of the bed that are at the same distance above or below the level of reference, and ZY will be the line of strike. Notice that AZ is determined by the depth of the bed in C and AY by the depth of the bed in B. A perpendicular from ZY to A,—the line DA will have the direction of the dip, and moreover AD:AY:AZ inversely as the true dip is to the dips (as measured in feet per mile) in the directions YA or ZA.

of transportation, and the elevations and profiles of railroads are taken carefully and are referred to lake level or sea level. Moreover in the "Dictionary of Altitudes in the United States," by Henry Gannett,* the altitudes of the railway tracks at most of the important stations through the state are given, and to connect these with the head of the boring will ordinarily be but little trouble. In fact, even without direct connection, inasmuch as the state is generally flat, and neither well-borers nor railroads are liable to choose the tops of hills, by substituting the altitude of the nearest station, which I have given with each well,† we are not likely to make a mistake of over twenty feet. At the same time, when wells are near together, this error becomes important and hinders decidedly the finding out of these minor flexures, which have great practical importance as accumulators of gas.

(*c*) A third error is in inexact measurements,—a positive error, whereas the previous ones were merely omissions. For a description of the manner in which measurements are made, we may refer to the Ohio report on Economic Geology,‡ merely remarking that there are several chances of error in the way that running measurements are taken, and there is evidence that errors do occur. For example, Mr. Charles L. Davis reports that when the Niles well was finished, it was supposed to be 1,140 feet deep, but proved on actual measurement to be only 1,099 feet. Numerous discrepancies may be noticed in the depths of other wells, when the measurements are derived from different sources or when the sum of the thickness of the beds passed through does not correspond with the total depth given for the boring,—discrepancies which are doubtless in part due to this cause. The records do not however give data to enable us to eliminate, allow for, or know definitely the size of this error. From various indications I judge that the percentage of error at Niles (4%) was not commonly exceeded, but was often approached elsewhere; the drillers are not likely to underestimate the depth of the well. This error is probably large enough entirely to disguise the other, made by taking the elevation of the railway track for that of the well-head, and seriously to affect our representation

* Bull. No. 76, U. S. Geological Survey.

† These altitudes are due mainly to Mr. Gannett, being taken either from his dictionary or from unpublished material kindly furnished by him.

‡ Geological Survey of Ohio, VI, 497.

of the beds, when the beds are close together. However, it is usual to take accurately with the steel tape the depths at important points, *e. g.*, where brines are struck.

(*d*) Another source of error consists in inexact descriptions. Of many of the borings no samples have been kept, and we have to depend upon the descriptions of those who attended the boring. Now, it is not always an easy matter even for an expert geologist to make much out of the ground-up particles brought up from the boring,* and it is not surprising if the drillers' records are very deficient.

I instance a few of the common mistakes:

Dolomite, [non effervescent (Ca, Mg) CO_3], is classed sometimes under limestone, sometimes under sandstone, but is rarely, if ever, recognized as dolomite. Anhydrite is never called anything but gypsum, is often overlooked entirely and called marl, etc. Anhydrite (or gypsum) in nature is always found where salt is. Not so in the records. Even geologists are apt to confound gypsum and anhydrite, the hydrous and anhydrous sulphates of lime. It is a noteworthy fact that at great depths in Michigan borings the anhydrous form occurs almost if not quite exclusively.

"Soapstone" is a loosely used term for calcareous shales and argillaceous limestones. It is a favorite term to apply to the Hamilton or Traverse Group.

Coal and black shale are sometimes confounded.

The term "sulphur" (as well as "sulphur water") is applied to water containing H_2S and smelling of rotten eggs, as well as to water that deposits sulphur, and to pyrite. Then there are other terms, such as freestone (by which sandstone is meant, although the material so called is not always sandstone), soapstone, flint rock, oil sand, oil rock, etc., whose meanings depend upon circumstances. Only those wells have trustworthy records where the fact is noted that samples have been deposited with the Survey.

(*c*) A final source of error is in the intermixture of the samples. This may be in two forms, either through accidental enclosures from the caving of an entirely different part of the column, or, if samples are taken but seldom, through the averaging up of perhaps a hundred feet of beds. In this latter case, if there

* See Rominger, Geol. Survey of Mich., III, 30, 117.

appear to be two distinct varieties of rock, their mutual relations, *i. e.*, whether they are interbedded in thick or in thin layers, may be quite obscure.

Considering all these errors together, it is probable that hitherto they have sufficed to render valueless any determination of dip from borings in the same immediate neighborhood; that they render the depth of a bed uncertain by more than 50 feet, but that they do not obscure the larger features revealed by the present borings as hereinafter described.

§ 4. Inasmuch as the material is thus imperfect, the only proper course to pursue is to put on record the data thus far obtained, quite apart from the conclusions that I have drawn, so that future workers with more and better data can draw further and more exact conclusions. Even as I write this report I am expecting well-records which promise to shed some much needed light.

But on a subject like this, where new facts are constantly being accumulated, a report must needs be journalistic rather than final, showing merely the state of knowledge up to some date; having for a main object, to point out where further work promises reward, and thus to lead to discoveries. Thus the more useful it is, the sooner will it become behind the times.

If those who are connected with well-sinking will see that samples are taken and kept on file (in the office of the Survey or elsewhere), that the depth of the well is accurately measured (at least when the boring is ended) and compared with the running measurements, and the location and altitude of the well-head are known, for the determination of which pacing and a barometric reference to the nearest railway are enough, we shall soon be able to prepare a much better report than this. And if ever the time comes that the drilling is done so as to bring out cores, and we have also a record of the temperatures of the rocks and of streams encountered by the drilling, such records will be of far greater value. Blanks for records and bottles for keeping samples have been furnished gratis by the Survey.

I have arranged near the close of this report an alphabetical list of all the towns in Michigan (and of a few of special importance in adjacent states), from which we have boring-records. This arrangement is the simplest, admits the insertion of new wells most readily, and makes it easy to look up what there

may be from a given town. In seeking to group by districts, one is sure to encounter some wells that belong as properly in one district as in another. Moreover one may see at a glance by reference to our map, whereon every town mentioned in the list is underlined, under just what town-names he will find the borings of a given district, which is convenient when wells are as numerous as they are about the Saginaw and St. Clair rivers.

Referring to this part for details, we begin then a general account of the rock series which will be pierced by the drill, and we naturally take them in the order in which they will be met, *i. e.*, the uppermost first. But of course the drill will strike in at different points of the series in different parts of the state. Accordingly, on the map (Plate LXXIV) are placed lines which show in general what I suppose would be the outcrop of some of the important division lines between different kinds of rock, if the soil and gravel and similar glacial or recent deposits were stripped away. Thus by noticing between which of these lines a given place lies, one can obtain an idea as to where in the geological scale he will begin, if he starts a boring. The same divisions are made, with some others, in the engraving of the geological column, which is mainly compiled from the wells at Jackson and at Monroe. We place by the side of our divisions those made by previous writers, and we shall discuss the differences as they come up. There are, however, two different principles of classification, the paleontological and the lithological, or classification by the remains of life in the rock and classification by the chemical and structural character of the rock itself, concerning which we wish to say something at the outset.

§ 5. The first step in the study of the earth's history, as it is written on tables of stone, was taken by Werner, or about his time, under the idea that different epochs of the earth's history were marked by the formation of peculiar kinds of rocks. Thus we get such names as Old Red Sandstone, Carboniferous, New Red Sandstone, Cretaceous, to denote periods of geologic time.

The second step was taken under the idea that by a series of creations, rocks formed during a given epoch, were characterized by remains of a life peculiar to that epoch, a life that was swept away by some terrible upheaval or cataclysm at the end of the epoch.

The third step in advance was taken when geologists began to realize that even as now in different places different kinds of deposits are forming,—in swamps, peat; at the mouth of the Mississippi, mud; on the coral reefs, limestone;—so it has always been. Hence the Old Red Sandstone in one place may correspond to a limestone elsewhere.

The fourth step in advance has just been taken in the realization by the paleontologists that, as now, so always, the kinds of animals and plants found in a given place or buried in a particular epoch vary, and depend not only upon their environment,—whether fresh water or salt, warm water or cold, muddy water or clear, shallow water or deep,—but also on more remote causes. Thus there are and have been zoölogical provinces, in which, under like conditions, very different assemblages of living beings have existed at the same time. Australia, South America and South Africa may serve as a present instance.

Thus we can rely blindly neither on the physical character of the rocks nor on fossil-lists. In either case we must also have an eye to what we may call paleogeography, and any classification we make will apply first and foremost only to a certain district. A final and universal classification and correlation of rocks according to time of deposit we can expect only from the use of both kinds of data, linked, if possible, to a chain of astronomical cycles.

It is certain that the zoölogical or paleontological provinces are much larger and more permanent than those districts for which there is a likeness in deposits. Yet within its confined district a classification by this method is as legitimate as one by that. Now, we shall find that the Lower Peninsula not only now belongs, but always has belonged mainly together in one basin, and that a distinct parallelism can be traced in the sections on the north, south, east and west sides of the basin, although, as has already been said, there is a great difference in these sections, due to an approach to a shore line on the northerly side. Of these sections we shall use as our type that farthest from the shore, for deposits along shore vary rapidly from time to time and from point to point, whereas any change that affects the deposits further from shore is likely to be wider-spread, and to mark a more sweeping geological or climatic

change. Moreover, among the changes which may take place in the character of the rocks, some will be found in practice to be farther-reaching than others and may also in theory be expected to be so. Conglomerates are notoriously local and variable, whereas the change from a clear sea-deposit to that of a sea supplied with the silt of a large river like the Mississippi, may be expected to affect an extensive area.

So too the contrasts between deposits of fresh water, of salt water and of very salt water will extend over the whole basin affected. It can hardly be expected as a rule that one part of a sea basin will be permanently quite fresh and the other part near saturation with salt. So that if there are marks of deposit from very salt seas, such as the scarcity of organic remains, and the prevalence of dolomite over limestone, or of precipitated limestone, siderite, anhydrite, salt, etc., these will be widespread. At the same time we must remember that there may be local exceptions at the mouths of unimportant rivers bringing in fresh water, and that while the condition of being concentrated to near precipitation may characterize a sea for a long time, very slight causes, such as the cold of winter or the spring freshets, the heat of summer, a series of dry years or some slight current, may suffice to check or to start actual deposition. The great deposits of salt at Stassfurt in Germany are divided by a series of lines of anhydrite into beds from 3 to 16 cm. thick, each supposed to represent a year's growth. We find at any rate in the basin we are considering, that while the general assemblage of non-fossiliferous (?) dolomites, marls, anhydrite and salt, forms a well marked series all over our district, we are not as yet able to trace any close parallels between different beds.

We notice finally another thing. In general, a new assemblage of living forms will work their way into a district in the wake of some geographic or climatic change that gives them a chance to replace the previous occupants. This geographic or climatic change will often leave its impress on the physical character of the beds and will thus mark a division line on both systems of classification. Often, however, the change takes the form of a prolonged battle between the old conditions and the old life, and the new conditions and the new life, first one side, then the other victorious at a given point. Thus we may find beds of the new physical character containing the new life,

alternating with beds containing the old physical character and the old life. Again, we may find several incursions of the new physical conditions before the old life gives way to the new, or, on the other hand, we may find the new life entering with the first occurrence of the new physical conditions, and persisting in spite of partial relapses to the old state of affairs. Such phenomena give rise to very complex problems, that may puzzle both the stratigrapher and the paleontologist, and may lead them with equal justification to draw their dividing lines at different points. We find, for example, at Goderich and Monroe (*q. v.*) an inroad of the Upper Helderberg conditions and fossils before the final disappearance of the Lower Helderberg dolomites. We find again, in the Traverse or Hamilton Group an era of struggle between the conditions of the limestone formation below and of the shale above, and in the Berea shale above the Berea or Richmondville sandstone we may perhaps see the last expiring effort of the Black shale to maintain its once extended dominion. In fact, the whole Waverly (in Rominger's sense) is a transition series between two periods, which, at their highest development, are easily contrasted. It is natural to find, as we do find, that these epochs of strife show the greatest variety of conditions at different points, provokingly enough, just where we wish to run our lines of division. A good illustration is the variation of the Richmondville or Berea sandstones in various wells. It should therefore be remembered, that while the great body of the formation above a given correlation line may quite certainly correspond throughout a given cross-section, there is quite a chance for error in the beds that immediately overlie it.

It may also happen that minor physical differences may occur quite independently of the general conditions of life and deposit. We find, for example, in the Silurian series beds of sand or sandy limestone or dolomite, like those of Sylvania, Ohio, or Ida, Michigan, composed of angular grains of pure silica, very free from alkalies, and hence admirably adapted for glass-making and of considerable practical value. This sand does not seem to have been rolled along, but actually transported by ocean currents. Now it is quite conceivable that a current like the Gulf Stream might slowly shift its course so as to deposit a sandy layer in the Atlantic, now on the American side, and

now toward the European side, while other changes of life and deposit were spreading from Europe toward America. If we look at the sandstones recorded in the Silurian, either from the wells between South Bend, Indiana, and Kalamazoo, Michigan, or from various points in Monroe county, we must assume for them some such origin.

If such a bed proves continuous from point to point, as it seems to be in Monroe county, it is proper and of practical importance to correlate it, even though this correlation line may cross some other. The two correlation lines will mark geographic changes that inverted the order of occurrence of the beds in different parts of the basin.

Mr. Winslow, State Geologist of Missouri, has recently,* in a valuable paper, to which I shall have occasion to refer again, dwelt on a similar phenomenon in coal formations, which we may also expect to find in our Coal Measures. The coal is liable to be built out as a swamp from the land, and to follow the horizontal upper level of the water, while a varied alternation of shale and limestone is deposited on the bottom and partakes of its gentle curvature. Thus the coal beds will appear to transgress the others slowly.

Inasmuch as the economic character, or practical value of a rock will depend more on its physical character than on the fossils contained in it, we feel quite justified in adopting a purely stratigraphical† division of the series; but as divisions may have only a local value, we should not lay too much stress upon them and should use for them only local names. This I have done in the geological column which is given herewith (Plate LXXIII), putting, however, in parallel columns, what I conceive to be the corresponding names and divisions of previous writers, and throughout the text, for the greater ease of the reader, often appending the older, more or less nearly equivalent names.

In my geological column, the column before the woodcut shows the local names that I use for the formations, with figures indicating their probable maximum and minimum thick-

* Bull. Geol. Soc. Am., 1892, III. 114-121.

† This we must do, in fact, in dealing with drillers' records, for without samples no paleontological evidence is possible, and even where samples have been saved, fossils are often absent, scanty, or interpretable only by an expert.

ness. The next column after the woodcut shows the names used by the Ohio Survey and largely by C. E. Wright. The third column shows those used by Rominger and the fourth those used by A. Winchell, and the fifth the probable grouping into systems.

CHAPTER II.

THE GEOLOGICAL FORMATIONS OF THE LOWER PENINSULA AND THEIR ECONOMIC PRODUCTS.

(*a*) THE QUATERNARY.

§ 1. The surface of the Lower Peninsula is, under the soil, covered with a layer of unconsolidated deposits that is commonly known in drill records as "drift" or "surface." This layer is composed of gravel of various degrees of fineness, mixed with boulders, and at times replaced by sand, marl, clay, etc. It is the product of the latest geological action, and is scarcely ever preserved in samples, so that it is useless to try to separate the parts belonging to the glacial, and those belonging to the terrace epochs. Nor are there data for discussing whether there are more glacial periods than one represented. The fact, however, that from a boring near Vassar, chips of beech-wood came up, and that wood was also found in a boring near Paw Paw, may be mentioned in this connection.

This layer of drift is entirely unconformable with the rocks beneath, and hence it is not possible to tell how far one must go to strike solid rock. This renders the exact position of the outcrops of the underlying rocks more or less uncertain. Take the Allegan well, for example. If there were only ten feet of earth to begin with, instead of over two hundred, it is quite possible that in the upper part of the well we might pass through the Marshall sandstone, which would thus extend somewhat further south than we are now justified in representing it.

Generally speaking, the drift is rarely over a hundred feet thick in the south and southeastern part of the state, but, as we go north toward Manistee, Frankfort, and Ludington, we find it much thicker.

It is often more or less stratified, and then the coarser layers are liable to yield good supplies of water.

At the very bottom there is often a layer of clay known as "hard-pan." As the drift lies unconformably on the other formations, this layer, where it occurs, will form an impervious covering on the edges of the beds beneath it. Hence it is, that often on striking through the drift to the rock beneath, especially if that rock be a black shale, we encounter flows of gas, which have been slowly oozing out of the bituminous rock and accumulating in any dome-shaped reservoirs that may be made by this impervious sheet.

Before leaving the group of unconsolidated deposits we may recount the different kinds of deposits known to be present, even although we cannot separate them in the well-records.

On top we have the alluvial deposits recently laid down by rivers, or by the wash of rains, or, in the southwest part of the state especially, the dunes of sand accumulated by the wind. We have also beds of marl and peat formed in small ponds. Then we have widespread terraces or beaches left by the great lakes when they stood at a higher level. Then there are gravel plains, kames, etc., left by the ice in retreat, as well as clays of about the same age deposited in lakes, and finally the moraine material, unassorted and often coarse and full of boulders, deposited at the front of or under the ice.

(*b*) THE COAL MEASURES — THE JACKSON COAL GROUP.

The most recent beds, below the unconsolidated surface materials, that will be met by the driller, will be found in the center of the state, as might be inferred by what we have said of its basin-like structure. They are the Coal Measures, in which small beds of coal rarely if ever over four feet thick are found. Very likely they never extended over the whole length of the state. They certainly were formed in very shallow water, not far from shore, and in consequence the exact order of beds varies rapidly from point to point, as Rominger remarks.* Not only that, but being so near the water level any slight lowering of the latter would bring them within reach of erosion, or if we imagine them an old delta deposit, the erosion might be accomplished by the main channel of the river, which from time to

* Geol. Survey of Mich. III. 126, 131.

time might have changed its course. Thus we get old river channels filled with sand cutting out the coal, such as are so clearly described in the report of the Commissioner of Mineral Statistics for 1881.* Obviously a boring striking such a river channel might present a section of beds entirely different from that 200 feet away, and entirely misleading. The section given from Corunna may be of such a nature. These river-channel sandstones are of common occurrence in coal measures.†

Besides the coal beds another rock of practical importance is fire-clay. Coal underlain by fire-clay, then by black, coaly shales and limestones, or beds of siderite (carbonate of iron), lighter colored shales and sandstones, with these makes up a set of beds separated by numerous unconformities. The common character of these beds lies in the abundant traces of vegetable matter in them and in the generally rapid variation in their composition, though they remain black or gray, not red colored, and always keep the marks of a shore deposit.

The series begins and ends with a sandstone often enough to justify, as it seems to me, the separation of these from the main group into an overlying Woodville and an underlying Parma sandstone. This has been done by Winchell, although Rominger doubts its propriety.‡ The imperfection of the records, of which I have already spoken, are far too great to permit any definite decision on this point as yet.

It has been suggested by certain authors, that as swamps would occur along the edge of a sea, so coal beds would occur most often near the margin of the coal basin. The positions of Jackson, Grand Ledge and Sebewaing rather favor this view, and point to a belt a few miles in from the margin of the coal basin indicated by the innermost line on the map, as most suitable for coal explorations. Corunna, however, where coal has been mined, is nearer the center of the basin, and there is also a report of five or six feet of soft coal in the well at Midland, only a hundred feet down. I hardly think that this could have been more than coaly shale, however, or steps would have been taken to develop it. Midland is near the center of the basin,

* Page 24. C. D. Lawton, under C. E. Wright.

† See Winslow's paper above cited, Geol. Soc. Am. 1892. III. 114. for cases in Missouri, and also Geikie's Text book of Geology, 1885. p. 467, for a well worked out system in the Forest of Dean.

‡ Geol. Survey of Mich., III, 128, 129.

and it will be seen that the coal of Michigan never lies far below the surface. In fact one of the serious difficulties of mining, one in which the center of the basin would have an advantage over the margin, is the lack of a roof strong enough to sustain itself and impervious enough to keep the water out.

The bottom sandstone of this series, *i. e.*, the Parma sandstone, is charged with a brine at many points, *e. g.*, at Bay City, where the brine the sandstone carries is distinguished from the next lower brine by a higher per cent of $CaSO_4$, etc., and a less per cent of the earthy chlorides (probably also bromides).*

There is no reason to believe that the Parma sandstone itself contains rock salt, and the brine may be supposed either to be the original salt water in which the sandstone was deposited or to have percolated up from the underlying saline beds, as the outcrop of these beds to the southeast is at a noteworthy elevation, and the water in the beds at the outcrop appears to be fresh. It is thus the first-met or uppermost salt horizon of the many which underlie Michigan. It varies rapidly in thickness and probably is bounded above and below, at least at many points, by unconformities due to erosion. It makes a transition from marine, intensely salt water deposits, to brackish or fresh water formations.

The character of the change would be fully accounted for by supposing the adjacent land to have been elevated so that it would condense more moisture and pour it into the sea out of the mouths of sand-laden rivers. Such a change would also account for the shoal-water deposits and rank vegetation of the Coal Measures. It should be said, however, that in comparing the well-records of Portsmouth and other points around Bay City, it seems likely that the "upper salt-rock" is not exactly equivalent to the sandstone in the deep Bay City well. At Portsmouth the upper salt-rock appears to have nearly the same position as the gypsum of the deep Bay City well.

(*c*) THE GRAND RAPIDS GROUP.

We pass next into a group of rocks composed of dolomite and limestone, and of gypsum beds with accompanying green shales, which indicate a shallow basin, from which the water was often evaporated faster than it was received. I do not know, however,

* Geol. Survey of Mich., III, 182, 183.

that rock salt beds have been found in this group, and by their absence it differs from the lower gypsiferous (Salina) formation.

Like most gypsiferous series, it does not appear to be at all uniform in character and thickness. On Rominger's map the breadth of outcrop varies widely, but that map is certainly inaccurate in some respects, as according to the coloring Sebewaing is on this formation, whereas it really belongs to the coal basin.

The shallowness of the basin is shown, not only by the great prevalence of ripple marks, but also by minor unconformities, such as one noted by Rominger on the Charity Islands.* It is probably unconformably overlain by the Parma sandstone, and perhaps in some places eroded away altogether. The following, however, appears as a common arrangement of the beds, beginning at the top:

First, Brown, veined dolomites.

Second, Light colored sandy limestones or calcareous sandstones, often flinty, often veined.

Third, Rapid alternations of sandstone, gypsum and shales, mostly light colored, which make up the lower part of the formation and were separated by Winchell into the Michigan Salt Group. The objections to retaining this name and group are, that no rock salt is known to occur in the beds; that the brines, which he associated with it, are really from overlying and underlying sandstones; and that, as Winchell himself remarks:† "This group is a mere local condition of the lower portion of the carboniferous limestone." Possibly Winchell grants too much in this, but at any rate in the well-records it does not yet seem practicable to separate the upper, more limey, and the lower, more shaly, part by a steadfast line.

(*d*) THE MARSHALL SANDSTONE.

Next beneath the group just described, which in its upper calcareous and lower gypsiferous beds is so well exposed near Grand Rapids, occurs a series of sandstones, very widespread and usually very easy to recognize in a general way, that have been the object of more detailed study than any other group in the state. The lower part of the formation, and the

* Geol. Survey of Mich., III. 119.

† "Michigan." 1873. p. 69.

beds immediately underlying it, in the sense in which we use the term, are rich in fossils and their casts, and have been the subject of detailed paleontological and stratigraphical investigation by Prof. Winchell. Prof. Winchell originally speaks of two groups,* an upper, Napoleon group, and a lower, Marshall group, the two lithologically not distinguishable, but the upper group non-fossiliferous. He seems later to have abandoned the subdivision and in his description and map made for Walling's Atlas, in 1873, as well as in the "Geological Studies" and in the chapter prepared for the American Geological Railway Guide (1878–1890), the Marshall group is given as the sole division. Rominger† considers Winchell to have overestimated the group by an error in the stratigraphy about Point aux Barques, denies that the presence or absence of fossils is a characteristic feature, and maintains that in fossils, *i. e.*, paleontologically, the beds under consideration are one with those of the group below, next to be mentioned, and hence refuses to recognize this group at all. How far this is justified from a paleontological point of view we shall not pretend to decide. It is a fact, however, in which all really agree, that the gypsiferous formation or carboniferous limestone (that is to say, what we call the Grand Rapids group), is underlain by sandstone, which often graduates into the shales beneath. If this were not admitted, the evidence from the borings would be quite sufficient. Its thickness varies, but it is generally from 50 to 100 feet. In the only two wells from which we have samples (Charlotte and Jackson) it is fine grained,—so that the individual rounded grains of sand and scales of mica can be seen only with the aid of a lens,—calcareous, friable, and gray, slightly greenish in hue, and, in contrast with the Parma sandstone, finer-grained and darker. This appears to be its common character, but at Napoleon, Stony Point and elsewhere, it is thicker and coarser. Winchell speaks of it as yellow and brown. This is probably an effect of oxidation.

The upper boundary of this sandstone is generally sharper than the lower.

Economically it is of importance, not only in outcrop, where it furnishes building stone, flagstone, and the Huron grindstones,

* Geol. Survey of Mich., 1860. pp. 80. 88. 138-141.

† Geol. Survey of Mich., III. 70-76. 86.

but also in being under cover the source of the Saginaw valley brines of Bay City, Saginaw, Midland and other places. It is thus the second salt horizon.

From a scientific point of view it marks the time at which the geological history of Michigan switches off from that of adjacent states and pursues its individual and peculiar course, so that any parallels drawn must be paleontological rather than stratigraphical. The Coldwater shales lying below the Marshall, and next to be mentioned, are stratigraphically continuous with and paleontologically (doubtless, at least in part temporally), equivalent to the Cuyahoga shales of Ohio. The Logan conglomerate, which caps the latter, corresponds, therefore, to the Marshall.

Thereafter, that is to say, for the rocks above this horizon, the basins were distinct, and we find in neighboring states no lithological parallels to the Grand Rapids gypsum beds.

In the beds next beneath the Marshall, there is a resemblance to the series found in Ohio. This continues through all the beds which come to the surface, down to those which outcrop in Monroe county, underneath which we find a closer likeness to the rocks of Ontario, except that the extreme southern part of Michigan belongs with the greater part of Ohio, and the extreme northeastern portion of Ohio with Ontario and with the rest of Michigan.

(*e*) THE COLDWATER SHALES.

This formation, which has numerous outcrops in Branch and Hillsdale counties, and is well exposed by the Coldwater River, from which I have named it, is a very bulky one, whose thickness geologists did not appreciate until it was revealed by borings. It consists of light colored, greenish or bluish, sometimes darker, shales, growing sandier toward the top and gradually passing into the Marshall. They are in zones more or less calcareous, and may have occasional bands of limestone, although nodules of kidney iron ore, of a brownish color, which in the well-samples appear as brown fragments mixed with the greenish shale, are more common, and are very liable to be mistaken for limestone or even, by drillers, for sandstone.

The Coldwater formation is never less than 600 feet thick, even if we exclude from it the Marshall at the top and the

Berea at the bottom. On account of its gradual transition into the Marshall sandstone Rominger has not separated them, but includes them both as Waverly, nor does he seem to have any definite line to separate the Coldwater shales from the Black shale beneath. That the top may be set at a brine-bearing sandstone, the Marshall, we have already seen. The Berea, the brine-bearing sandstone of Sand Beach, White Rock, Port Austin and Oscoda, which was long ago recognized by Garrigues as an independent horizon, furnishes an appropriate base, of which we shall treat in its place.

The succession of beds between these two horizons is in general quite monotonous. Traces of fossils are rarely if ever discernible in borings, but this may be due to the fact that the rock is very soft and friable, and so crumbles that the fossils are obliterated.

Toward the west and northwest this formation undergoes a change, which makes its lower boundary much less distinct. We find no distinct sandstone at the base, but at two horizons, one about 200 or 300 feet, the other about 500 feet, above the bottom of the Black shales we find red shales which represent sandstone, and are somewhat charged with gas, oil or brine, according to circumstances.

(*f*) THE RICHMONDVILLE SANDSTONE.

This formation, which may as well be called Berea, as it is much better developed in Ohio — at least so far as outcrops are concerned — is nevertheless of great practical importance in this state, as it supplies the salt wells of Tawas, Oscoda and of Huron county. It is also reached by deep wells at Bay City and Blackmar. It is thus the *third* salt horizon.

At Muskegon petroleum and gas are said to have been observed at about 500 feet above the bottom of the Black shale. This occurrence, however, is probably in the Coldwater proper, as one marked feature of the Berea is its disappearance toward the west of the state, where another zone some 200 feet above it, grows in importance; north and south the Berea is comparatively uniform. The cause of its origin and greatest development is evidently to be sought in the elevation of the east side of the basin, while the upper horizon may mark a slight elevation of the west side.

In the southeast part of the state it is a coarse, gray sandstone about 100 feet thick, and under Pontiac apparently thicker. It was first (?) recognized by Rominger at Ann Arbor (see Ann Arbor well-record), and according to Wright crops out at Richmondville on Lake Huron. This is the only outcrop recorded in the state that I know of, unless the outcrop at Brown's Station mentioned by Rominger* be such.

This is the horizon of one of the Pennsylvania oil sands, and, since at different points in Michigan, it is overlain and underlain by bituminous shale, it would surely be an oil or gas producer, if the right structure of upward flexures for accumulators or reservoirs could be found. As we have said, our records are too imperfect to enable us to determine this point with absolute certainty, but the sections suggest as favorable for experiment, a region near Tawas, one between Caseville and Romeo, and one southwest from Saginaw.

Small gas reservoirs, as previously mentioned, are sometimes formed where the line of outcrop of the formation is covered with glacial clay.

Along the west coast the red shale that marks the place of the Berea, is probably either the underlying Bedford shale, which is often reported red in northern Ohio, or the overlying formation stained this color by chemical action. Red shales are often associated with brines.

The Richmondville brine is at the greater depths, *e. g.*, Port Austin and Oscoda, strong and rich in $(Ca, Mg)(Cl, Br)_2$, their ratio to Na Cl being about 1:3. This brine nearer the outcrop at Sand Beach and White Rock is on the other hand exceptionally free from earthy chlorides, and forms an excellent salt brine.

(*g*) ST. CLAIR SHALES.

This group represents one of the most characteristic and most widespread formations of the Mississippi Valley.

The name Huron shale has often been applied to the same series of rocks, but, as the table shows, was used by Winchell in a much broader sense. The name Ohio shale also covers

* Geol. Survey of Mich. III. 83.

pretty much the same ground.* The group consists of a series of dark shales growing darker and more bituminous toward the bottom. The bottom layers generally burn with an aromatic smoke. Pyrite occurs and readily decomposes, frequently yielding sulphates of a puckery taste, like that of alum, and sour smell. This group is widespread not only within but without the state.

On the shore of Grand Traverse Bay and on Sulphur Island, in Thunder Bay, lying under the surface drift deposits of St. Clair County and River, and pierced by many borings there and all over the southern half of the state, it is easily recognizable and tolerably constant everywhere, although, as Canfield and Wheeler's boring at Manistee shows, it appears to be less black and bituminous towards the northwest, in which region also the Berea shale is absent. It seems as if the conditions that attended the immense luxuriance of vegetable matter which characterizes this formation began to prevail over the whole state at the same time, but lingered much longer in the southern part of the state, even till after the epoch marked by the Berea sandstone, and produced the black Berea shale, while in the northern part said conditions were relatively transitory, so that both the underlying and overlying shales gained at the expense of the bituminous. This formation, with the bituminous matter in it, is one of the great sources of gas and oil, which, if conditions are favorable, may accumulate in beds overlying and underlying it, and if the outcrop is covered with impervious clay, oil and gas may accumulate there, producing shallow wells. I copy from Mr. Wright's notes some entertaining accounts of the behavior of such gas wells near the St. Clair River.

On W. H. Stevens's farm one well was bored 250 feet deep, when a large flow of gas was struck. Mr. Stevens noticed something queer about the smell of the well, though he did not suspect that there was gas, as he was looking for water. As he struck a match to light a cigar he was immediately surrounded by flames. The workmen ran away and went into a barn. The gas from the well taking fire began to blow out sand and

* Brumell. Bull. G. S. Am., 1893. IV. 227. calls them Portage. This paper gives valuable details as to wells in Ontario. and announces a forthcoming publication of the Canada Survey. *q. v.* It has been published since this report was written. It contains descriptions of wells and formations harmonizing with ours from the Devonian down.

boulders, some of the latter as large as a man's two fists. As they came dashing through the roof of the barn they caused the men to leave it at once.

The stream of mud, sand, water and gas shot upward for a long distance, the water from 50 to 100 feet, where the gas seemed to separate and ignite in a solid column 30 to 40 feet in diameter, reaching upward for a long distance. A newspaper could be read a mile away even on a dark night.

After the boulders ceased to blow out, the men succeeded in driving a plug into the "casing pipe." On the end of a casing pipe was a T with a cock on the horizontal branch. After the vertical outlet was securely closed they opened this cock and permitted the gas to escape from the horizontal pipe and lighted it again. The flame shot out 200 feet, passing over the railroad track. In the evening the train came along and whistled "down brakes," and did not care to proceed until Mr. Stevens and the train men had walked along the track under the flame to see that it was perfectly safe. In the spring of 1885 the gas was shut off and securely fastened for fear that it might burn everything during the dry season.

Antoine Halin had a farm two and a half miles west of Marine City, and in 1877 or 1878 he struck gas, which did not smell of sulphuretted hydrogen, in a hole 130 feet deep. It blew with great force and formed a cavity 15 feet across, but after several weeks gradually weakened, and, though still yielding a little gas, is used as a fresh water well. The gas came from between the rock and the clay and blew out one stone eight inches in diameter, and made a pile of sand three feet deep for 20 feet around.

He burned it in his house for three or four years, although when one rock came through the roof of his house he was very much frightened and thought the devil was after him, and would have taken a very small price for his farm. The ground trembled for some distance around and the roar could be heard for two miles.

So also four and a half miles west of Marine City, the same distance south of Port Huron, near Swan Creek, and in other places in the neighborhood, wells down to the rock have furnished gaseous fuel for some years.

Another similar well is at Norris, near Detroit.

(*h*) THE TRAVERSE GROUP.

This group of rocks may be said to form the transition between the St. Clair and the underlying limestone. The change from the black bituminous shales is generally well marked, especially as the upper part of the formation is more calcareous than the lower. Very frequently on striking through into this formation a flow of highly mineralized water is struck, which is too impure for a salt brine. A more markedly pervious horizon is at the base of the group. Lithologically the formation may, in fact, be considered very well marked and consists of bluish calcareous shales and limestones or dolomites, which lie below black bituminous shales and above a yellowish cherty limestone. While the formation as thus defined can be traced all over the state, it varies enormously in thickness and is very possibly not everywhere equivalent in time. It is perfectly conceivable that the conditions producing this group lasted longer in the north than in the south and that the black shale formation came in later. Such reasons make a local name preferable to that of Hamilton. Winchell used the name Little Traverse, but it seems to me that the prefix "Little" can be dropped, inasmuch as the outcrops of both the Little Traverse and the Grand Traverse, the names applied by the early voyagers to the short-cuts across the mouths of the two bays which indent the northwest coast of the peninsula, belong to this group. Its outcrops are unknown in the southern part of the state, so that Rominger on his map entirely omits it there. N. H. Winchell, in the Proc. of the Am. Assoc. for the Adv. of Science* gives an account of the different views as to the boundaries of the formations in that region.

We find no difficulty in recognizing in the well-borings, at least 80 feet of this group as defined above, and by the time we have got as far north as the St. Clair River we find it has thickened to over 300 feet and is subdivided as follows:

2 feet hard pyritiferous argillaceous limestone.
12 feet shale, "soapstone."
80 feet limestones, "top limestone," often gaseous.
150 feet shale, "top soapstone."
4 feet limestone, "middle limestone."

* 1875, II. 57.

65 feet shale, "lower soapstone."

Beneath the latter are light-colored limestones yielding gas.

The "middle" limestone is not always recognized, and the shales are calcareous, so that we may consider them as alternating calcareous shales and argillaceous marls or limestones. The 14 feet of transition beds on top often seem also either to have been overlooked or to be absent, but the division into a top of limestone and a bottom of shale we can trace throughout the state.

By the time we get as far north as Alpena, the formation appears to be nearly 600 feet thick.

This formation gives a case where, according to the accounts quoted by N. H. Winchell, hereinbefore mentioned, the life of the Hamilton period begins its continuous existence before the general conditions of the Corniferous time are finally routed.

(*i*) THE DUNDEE LIMESTONE.

This name is nearly equivalent to Corniferous or Upper Helderberg. Lithologically the upper limit of the formation is one of the sharpest lines we have, separating a great series of bluish grey or black, largely argillaceous rocks, from a great series of buff, yellow or almost white, largely calcareous ones. It probably marks some geographical change from a dry climate to a wet one and from a sea of clear water to one more or less tinged with mud and floating algæ. The paleontologists, however, as may be seen by N. H. Winchell's paper already referred to, are not agreed as to this upper limit and, as we shall see in a moment, there is a very serious difficulty in fixing its lower limit. We therefore prefer to take a local name, defining it as extending down from the bluish beds of the Hamilton so long as the formation continues to be limestone, stopping with the appearance of dolomite or of gypsiferous shales.

As thus defined, it is widespead, easy to recognize, and quite uniform in thickness and character. Its thickness remains not far from 100 feet, running up to 160 feet.

It is generally very light-colored, yellowish, effervesces very briskly in acid, and leaves a harsh, cherty residue. It is almost always saturated with a strong but impure brine. On penetrat-

ing it from the overlying Hamilton shales we encounter frequently oil or gas. It is supposed to yield the oil at Petrolea, Canada, and yields oil in Michigan wherever we find the proper structural conditions. In spite of the strength of the brine (*e. g.* at Charlotte it has a Sp. Wt. of 1.198) it is also so impure that in the presence of so many better ones, it has no commercial importance as a source of salt, but has importance from a medical standpoint, and as a source of chemical industries.

This formation is well known in the outcrop, not only in the Mason Creek quarries and elsewhere in Monroe County, but also skirting the northern end of the Lower Peninsula to Mackinaw City.

Winchell has distinguished an upper oölitic and a lower agatiferous and brecciated part, but this division is not marked in the borings. Winchell has also been corrected by Rominger in the assumption that this group appears in the extreme southwest part of the state, and the borings at Niles and at South Bend, Ind., show that this correction is just. Fragments of fossil brachiopods are common in samples from this formation (See Allegan well), and the samples are more characteristic than those from any other horizon except possibly the Black shale.

The line between this formation and the one below it, being one between limestone and dolomite, can be ascertained only by the use of acid. Hence it is commonly overlooked by drillers and cannot be determined in wells from which we have no samples. But it is very often marked in outcrop by a brecciated or conglomeratic zone. Generally we reach dolomite before the formation becomes gypsiferous, but, as in Morley's well at Marine City, and perhaps at Charlotte, this does not seem to be always the case. We may have gypsiferous limestones. In such a case to connect the gypsum is about as justifiable as to connect the tops of the dolomites.

(*j*) THE MONROE BEDS.

This name may well be taken to represent the oldest beds that come to the surface in the Lower Peninsula. Not more than 100 or 200 feet of these beds are exposed at the surface, but borings reveal a thickness of even more than 1,200 feet, which

we are not yet able to subdivide. It may be defined lithologically as extending from the limestones of the overlying Dundee down to the lowest gypsiferous beds, and to consist mainly of buff dolomites and of calcareous and argillaceous marls, associated with anhydrite and rock salt. Both of the latter are white when pure.

An interesting feature is the intercalation, in the upper part of this formation, both at Goderich and at Monroe, of a group of beds which lithologically and, according to Hunt, in fossils also, resemble group (*i*)—the Corniferous.

The period of the Monroe beds is that of the Salina and Lower Helderberg. At that time Michigan was covered by an excessively salt sea which stretched from Wisconsin to New York, was bounded by a continent on the north and east, on the west by low land in Wisconsin (the edge of the Helderberg is found barely extending to just north of Milwaukee), and on the south by a great bar, or reef, or flat in Ohio, which seems to have been just awash. This is indicated by the prevalence in the Ohio Helderberg, not only of ripple-marks, but also of mud cracks and of brecciated and conglomeratic layers. If we imagine tides like those of the Bay of Fundy rushing over this flat, producing this breccia and conglomerate and bringing fresh supplies of water to the enclosed sea, and furthermore that the sea was exposed to a hot sun and received but little accession of fresh water from rivers—this latter is shown to be true by the scarcity of mud and sand—we have the conditions of the Helderberg or Monroe deposits, conditions which are evidently favorable to the formation of a sea charged with salts.

The bed or beds of sand suitable for glass-making, already mentioned, seem sometimes to be derived as a residue from the dissolution of a siliceous dolomite. This sand shows by the frequency of perfect minute double ended crystals of quartz that recrystallization has gone on to a great extent. These sands mark the course of currents and perhaps also the result of rehandling and recrystallization of flint derived from siliceous organisms.

If a line be drawn, leaving Muskegon and Wyandotte on its northeast side, Monroe and Kalamazoo on the southwest, we may say that south of this line no rock salt has been discovered in this formation, although concentration proceeded far enough to

lead to the deposition of sulphate of lime and the concentration of brines. This region then belongs with Ohio. But north of this line it is probable that this formation yields rock salt almost universally. The thickness of rock salt at Wyandotte and along the St. Clair River is over a hundred feet, and at Royal Oak it appears to be over a thousand.

These figures need excite no incredulity, as there are vastly thicker deposits in Germany. They only excite the query whether somewhere there may be found deposits of those salts which, being most soluble, are latest to crystallize, like those deposits which have made Stassfurt the storehouse of the world's chemical industries. Such analyses as those of Sand Beach indicate a concentration of sea water nearly to the point of precipitation of the Stassfurt salts. Such deposits, if they occurred, would be expected in the upper part of the formation.

These salt deposits should rise again proceeding to the north, and, in fact, just north of the Straits of Mackinac, gypsum beds do outcrop, while at St. Ignace a thin bed of salt is reported only 400 feet below the surface. At Alpena they are about 1,200 feet below the surface. Near Cheboygan they should be sooner reached. The salt industry will doubtless, in time, work north.

The upper beds outcropping in Monroe county are ash-colored and brecciated in some places, marked with acicular crystals (gypsum), which readily weather out and leave cavities.

Thick as this formation is, we cannot sharply subdivide it, although, as I have said, it doubtless includes the series called Salina in New York, as well as the Helderberg. However, in the section between Monroe and Goderich we may perhaps divide it as follows, in descending order:

At the top a series of dolomites or gypseous marls, marking a time of desiccation, underlain by limestone frequently passing into a calcareous sandstone; beneath this sandstone some more beds, gypseous or even salty, marking a second time of desiccation, and after two hundred feet or more of somewhat gypsiferous dolomites, a rapid succession of thick salt beds, marking the first and greatest period of desiccation. The boundary line between this formation and the Niagara underlying it is far from well marked.

(*k*) NIAGARA AND CLINTON.

These formations are struck in well borings only at the extreme south and north of the district under consideration. The most characteristic part probably belongs to the Guelph formation, being a dolomite or dolomitic limestone, very fine-grained and very light colored. In fact the powder is almost white. The description of this formation would answer well to that given by Orton*, and, in accord with what he says of the change in passing from southern to northern Ohio, we are not usually able to distinguish between the lower part of the Niagara limestone and the Niagara shale. The latter shale, however, we identify at Wyandotte. Generally toward the bottom of the series the limestones become more ferruginous. (I may remark just here that from all the samples of the borings the magnet will extract at least a small quantity of black magnetic oxide of iron which is, I imagine, derived from the drill.)

From the horizon just mentioned we have "red rock" at Wyandotte, but at Monroe it is very indistinct and at South Bend, Indiana, it is no plainer.

This formation is at the bottom of and marks the beginning of a great period of limestones and dolomites, formed in an era when the waters of the sea were clear and deposited but little detrital matter. Very possibly there was then a dry climate, for this would not only check erosion on adjacent land but assist in the evaporation necessary to produce those beds of salt and gypsum which mark the Helderberg. There seems to be a certain symmetry of arrangement, with this series of salt and gypsum as a center, *i. e.*, dolomites above and below, next to them limestones, then shales and black shales, which may indicate that salt and gypsum represent the culmination or maximum in some great variation either in climate or in geographical conditions. The evidence points rather to a steady progression in geographic conditions, and this renders the theory of an epoch of dryness at least plausible. The facts to which we have called attention are, of course, practically the same as some from which Newberry derived his conception of cycles of sedimentation.

While the top of the Clinton and Niagara is ill defined, the bottom is well defined. Only at Wyandotte does the drillers' log

*Geol. Ohio, VI, 13-15.

seem to give us alternations between this formation and that below it—the Medina.

(*l*) MEDINA SHALE.

This formation is grouped generally and by paleontologists with the formation immediately above it. In our state both lithologically and in the drillers' records, it is quite as likely to go with those below it. It is really a transition bed. Its red color and ferruginous nature link it with the beds above, its argillaceous character with those below. We know that it occurs farther east, in New York, as a sandstone, and we compare it with the Berea, which in the eastern part of the state is also a sandstone, but further west is represented by a red shale.

In northwestern Ohio, 50 to 100 feet of it are reported, and it continues north unchanged, as a series of red and green shales, as far as Monroe. From Wyandotte we have only the drillers' record, which is not to be safely interpreted.

(*m*) HUDSON RIVER SHALE.

When once we have fairly pierced the shales of the Lower Silurian, the color of the formation changes to the more usual one of green and bluish gray. The shales are more or less dolomitic or calcareous. After descending three or four hundred feet they become darker, and we may consider that they are passing into the next group.

(*n*) UTICA SHALE.

This is brown or black and is not unlike the St. Clair shale. It is thought to be one of the great oil and gas producers of adjacent states; the product collects on the under side (?).

In this state, however, the formation lies excessively deep, and has been reached but once in the Lower Peninsula. Unless the signs of a favorable geological structure should be plain, the large cost of exploring through it to the Trenton beneath would not be worth while. One or two borings sunk in the north part of the state to see how deep it really lies, would, however, be of great scientific interest.

(*o*) TRENTON LIMESTONE.

This formation reached in borings at Monroe and South Bend appears as in Ohio, and is really a dolomite; it is buff, shows

traces of gas, and is charged with brine. It is the great oil-bearing and gas-bearing stratum of Ohio; but even there it does not produce them unless the other conditions are favorable. It is practically unexplored in this state, and there is little encouragement in attempting to pierce to the enormous depth necessary to reach it in the only places where there appears as yet any hope of finding the requisite structure for the collection of gas and oil reservoirs.

ECONOMIC PRODUCTS.

§ 2. Having thus run over the different formations, it seems worth while to make some general remarks about the valuable products thus disclosed. Building stones will not enter into consideration, because they can be worked to advantage only from the surface, and require large samples to determine their qualities.

(*a*) Coal also must lie reasonably near the surface to be available, and indeed in our state it lies only too near. By reference to the map it will be seen that there is a considerable area of Coal Measures in the state, not all of which can, however, be expected to produce coal in paying quantities; much of it is, as yet, entirely unexplored. The seams of coal have never proven much over four feet thick, yet there is enough coal in the state materially to regulate the prices set by outside corporations. It is all soft bituminous, it need not be expected below the first two or three hundred feet of rock, and is apparently more liable to "wants" than to faults. That is to say, if a coal seam fails at one point it is more liable to be found at about the same level on the other side of a channel filled with sandstone, than at some higher or lower level.

(*b*) Plaster has for a long time been a staple article of production in Michigan. Our records show that there is enough to last for a long time. Between Grand Rapids and Alabaster Point there is a strip of country that can furnish supplies of it for ages. Not only that, but about St. Ignace another set of beds come to the surface that underlie the whole Lower Peninsula, are in many places very thick, and can be worked whenever and wherever the cost of sinking to them is not too great. At great depths wells show the plaster to be in the form of anhydrite. It is not

absolutely settled whether this is formed by precipitation under pressure, or by exposure to heat.*

(*c*) The mineral waters and sanatoria of Lower Michigan, while not perhaps world-wide in their reputation, have, some of them, a more than local reputation. Many of these depend not on real springs, but on wells or artesian borings. Quite a number of analyses have been collected by Dr. Albert C. Peale.† We can easily divide them into three groups, with one or two apparent exceptions.

The first group contain free H_2S, are the "sulphur" springs, and draw their water from below the St. Clair black shales, probably in most cases from the upper Helderberg or Dundee, which almost always yields mineralized water very freely. Analyses of such water show, beside the free sulphuretted hydrogen, some salt, the other chlorides and the bromides in very small quantities, and the sulphates predominating over the carbonates. In this group are the Alpena Magnetic, the Ypsilanti, the Mt. Clemens, and the Wyandotte wells, and the sulphur springs in Ash township, in Exeter township, near La Salle, Monroe and Raisinville Monroe county, and in Brownstown township, and at Dearborn, Dundee, and Gibraltar, in Wayne county, and also at St. Clair. These, as we see, all lie on the margin of the basin. The Sand Beach deep well belongs in this group, but is unique in its large yield of KCl and $Mg\ Br_2$.

The second group contain CO_2, if any gas, and little else beside carbonates; they are, in fact, common hard waters. They occur mainly within the coal basin. Such are the springs at Hubbardston, Leslie, Otsego, Owosso, St. Louis, and Bay Port,‡ and Warner's spring at Albion.

Such wells will be classed as carbonated, chalybeate or calcic.

The third group consist of more or less impure brines, containing mainly or largely sulphates or chlorides. This group are largely wells, and lie nearer the center of the basin than the first group.

* See Neues Jahrbuch. für Geologie. 1887. II. p. 292.

† Lists and Analyses of the Mineral Springs of the United States. 1886. Bulletin No. 32 of the U. S. Geol. Survey. pp. 145 to 149.

‡ Analysis by R. C. Kedzie. per imp. gall. = 70.000 grains:

$Ca\ CO_3$	10.36
$Mg\ CO_3$	1.14
$Na\ Cl$	.50
Total Solids	12.00
H_2O	99.98 per cent.

Their composition varies a good deal, according as chlorides of sodium, potash, magnesium or calcium, or the sulphates of calcium or magnesium predominate. In this group belong the wells at Eaton Rapids, at Fruitport, at Lansing, at Midland, at Spring Lake, and Butterworth's spring at Grand Rapids.

Many of the waters of this last group might be used for the manufacture of salt (although they are rather impure for this purpose), and so they lead naturally to the consideration of the most important geological product of the Lower Peninsula.

(*d*) Some kind of a brine commercially valuable for its salt is found in every porous bed which we strike at a depth great enough to prevent its being leached out by descending currents, notably in the Parma sandstone at the base of the Coal Measures, in the Marshall, in the Richmondville, or Berea, and in the Salina. The quality of the brine is different for the same horizon at different places, yet not entirely without law, as we shall endeavor to show.

In the first place the slow leaching out, due to descending water, will tend to make the rock near the outcrop less salty. This water will not go very far, however, if there is no place for it to go, to produce a circulation. As Michigan is a comparatively undisturbed basin, this action has not gone far, and at low points in the outcrop of the basin salt springs may be found.

Another cause for the different composition of brines may be found in the following considerations. A column of sea water will not have the same amount of salts in it at all parts. This is true of the sea itself. There will be a tendency for the salts to be more concentrated in the lower part. Not only that, but the percentages of the various salts will not be in the same ratio, the heavier salt having a tendency to gather at the bottom, although the actual amount present has a modifying influence. Now, it seems probable that the same action will go on slowly in a porous bed of brine-bearing sandstone, so that we shall get the stronger and more impure brines from the deeper parts of the basin. If we look at the records of White Rock, of the upper horizon at Sand Beach, and of Port Austin, as given by Garrigues*, we shall see a steady increase in the ratio of $MgCl_2$ to NaCl, with the depth of the Richmondville. So, too, East Tawas and Oscoda, the lower horizon of Sand Beach, and the St. Clair wells, show

*Geol. Survey of Mich. III, 183, 184.

the same thing. If this is true, the brines richest in bromides would be found near the center of the basin. Another thing that may affect the brines is the original composition of the sea. It is easy to perceive, for example, that inasmuch as gypsum is first precipitated, a sea which has long been depositing gypsum beds, but never got so far concentrated as to throw down its salt, will have less $CaSO_4$ than usual. The beds in which the gypsum was deposited will have an excess, and those above will have a deficiency, of $CaSO_4$.

Around Bay City the brines from the Marshall formation show less gypsum than those above, from the gypsiferous Subcarboniferous, as Garrigues long ago remarked. Undoubtedly, however, the best brines come from beds of rock salt. Such rock salt brines are furnished by the deep wells of the St. Clair district, of Alpena, Manistee,* Ludington, and the northwest coast. In pumping all such brines, care should be taken either not to bore down into the bed of gypsum, that always lies underneath, or to stop off the gypsum, as well as to stop off any impure brines that come from higher levels. Salt beds will probably be found by any borings north of a line from Wyandotte to Muskegon.

(*e*) As we have already noticed, the brines of our wells and mineral springs contain a good deal beside pure sodic chloride, and the mother liquor left after the precipitation of the salt might find a variety of uses, if it were economical to separate the different salts. The only product which it has been found worth while to save hitherto is the bromine. As this sells for 25 cents to 35 cents a pound, it has considerable value. Bromine and bromides are heavy, and accordingly we expect to find them in the center of the basin most richly. We are not surprised then to find that Midland is the chief seat of the industry. Two new wells have just been put down solely for the bromine. Bromine has also been manufactured in East Tawas. The bromine at Midland is derived from the Marshall group, which, as we have already noted, is rich in $MgCl_2$, with which the $MgBr_2$ would be naturally associated. I append an extract with an analysis from the Tenth

[*The following is an analysis of the Canfield and Wheeler brine, by Albert H. Prescott, showing that it is an excellent brine for salt making; Sp. Gr. at 60° F., 1.20054]:

H_2O	73.80
$CaSO_4$	0.4395
$(Ca, Mg)Cl_2$	0.3449
Total solids, rest mainly $NaCl$	26.20
	100.00

Census Report*. As regards the East Tawas works, we have no details. The other waste chlorides have uses as disinfectants, as bases for chemical and pharmaceutical industries, as fertilizers and in the various uses mentioned by Garrigues.† I have already suggested the possibility of finding deposits of these more soluble sea salts.

(*f*) Oil has been much sought for, but as yet with no great success. The difficulty lies rather in the structure, than in the nature, of the rocks. To be sure the Trenton, the great oil- and gas-bearing horizon of Ohio, lies buried so deeply under most of Michigan that it is hardly at all explored, only a well or two in the extreme south of the state having reached it. Yet the horizon of the Dundee or Upper Helderberg is more accessible and has been reached all over the state. Now this is the oil-rock of the (Petrolea) Canada oilfield, and almost invariably we encounter traces of gas and oil in it in this state. So, too, in Pennsylvania the Subcarboniferous has several oil sands, and in this state traces of oil and sand are met with in corresponding levels. The real difficulty seems to be that oil and gas will gradually work their way out to the outcrop and escape, and not collect in any quantity, unless there are little folds or at least terraces in the porous strata, in the top of which they may collect. These do not need to be very prominent, as is shown by the way the gas occurs in Ohio.

Now, the general structure of the Lower Peninsula being that of a basin, we can expect oil or gas only where there is some minor undulation, enough to overcome the general dip. Are there any such? I cannot say positively, but from the best evidence before

* Vol. II, p. 22. Rowland on the manufacture of chemical products and salt. Samples taken in 1880, from Midland, Michigan, and analyzed by Mr. Ayers, at the university of Michigan, resulted as follows (specific gravity, 1.2557):

	No. 1 Per cent.	No. 2. Per cent.
Sodium chloride	5.5754	6.0801
Calcium chloride	14.3574	14.5859
Magnesium chloride	3.9263	3.4019
Magnesium bromide	4 8356	4 8356
Calcium sulphate	0 0160	0.0160
Water	63.3941	63 3941
Total	92 1048	92 3136

At Pomeroy, Ohio, about one ounce of bromine is obtained from a gallon of bittern, or one pound for every two barrels of salt made. The salt brines of the United State are richer in bromine than those of any other part of the known world, and now furnish large quantities for exportation. Home competition has lowered the price until the profits of the business have been reduced to a very small margin. Since the census year the manufacture of bromine has been started at Midland, Michigan, with considerable success.

† Geol. Survey of Mich., III, 216.

me, not having been on the ground, there appear to be minor flexures running south from Point Aux Barques and about Tawas City, and also in the center of the basin. To reach the latter would require the deepest wells, and on the whole the anticlinal indicated just west of Clifford appears to me to be the most favorable position for experiment. It is known that the gypsum and salt deposits are very irregular and it is not impossible that underlying them in the northern part of the state may be pockets of gas or oil. In any event, in view of the fact that heavy brines are so frequently to be encountered, it is necessary that they should be cased out or they will drown out lower seams of lighter material.

(*g*) Almost the same remarks that apply to oil apply to gas, except that it is worth noting how often gas collects in pockets under the drift along the outcrop of the Black shale.

Such wells, not wasted, may last for quite a while and pay for the labor of piping them. They will of course furnish only a house or two with light.

I wish to emphasize the fact that with regard to gas and oil wells, the occurrence of any particular bed is of less importance than the structure of the beds. There are many horizons in the paleozoic rocks of this and of adjacent states and of Ontario that yield traces of oil and gas, and the horizon that in one region is very productive is in another barren, as is also noted by Brumell.*

§ 3. The State Geological Survey is anxious to secure samples of all well-borings, and for this purpose will furnish the necessary material in the shape of bottles, boxes, corks, printed blanks, etc., for the preservation of such samples and their records, and in return for samples sent to it will furnish a report on their character. In order to help improve the records of the drillers and to enable the latter to keep themselves posted, we append a few hints on the determination of samples from deep borings, hoping, however, that this will not lead drillers to neglect correspondence with us.

(*a*) The tests suggested are the simplest possible and require the use of material obtainable anywhere, namely:

A candle or lamp;

Some strips of glass about an inch wide and three or four

*Bull. G. S. A. 1893. IV, 234. et passim.

inches long, such as are used by doctors to lay objects under the microscope; or watch-glasses will do;

Acid: Citric acid, the crystals of which may be carried around dry and a small quantity dissolved when needed, will be very convenient; dilute muriatic acid, or strong vinegar will do;

A pocket lens.

(*b*) The more important substances to be recognized are:

Silica, SiO_2, in the form of quartz-sand or of chert. Chert is a translucent, sometimes impure mixture of chalcedony or opal, and of quartz, of organic or of chemical origin. A rock composed mainly of quartz-sand is called sandstone or freestone. If a rock contains merely a little sand it is called arenaceous. A rock containing chert is called cherty or corniferous.*

Carbonates, of lime, magnesia, or iron (Ca, Mg, Fe), CO_3. Rocks composed of these are called, in general, limestones. If they contain merely a small amount of carbonates they are said to be calcareous or calciferous.* If the limestone contains magnesia it is said to be magnesian, or dolomitic, and when it consits of about half carbonate of magnesia (21.7% MgO) it is called dolomite. A certain amount of iron carbonate often occurs mixed with the other carbonates and is not mentioned, but it also occurs in bands or rounded masses of kidney iron ore in many shale formations.

Clay, a chemical and extremely fine mechanical mixture of silica with alumina and water, is the main material of shales. When there is only a small amount of clay in rocks, they are said to be argillaceous.

Coal, in Michigan always more or less bituminous, is mainly carbon. As the per cent of impurity, or ash, increases it is called coaly or carbonaceous, then bituminous and lastly black shale.

Salt, Na Cl, either massive as rock salt, or as brine; has with it,

Gypsum, hydrous sulphate of lime (Ca S O_4. 2 aq.), or—

Anhydrite, anhydrous sulphate of lime (Ca S O_4), *i. e.*, "plaster." These are not commonly distinguished from each other, and beds containing them are known as gypseous or gypsiferous.

Limonite, or yellow ochre, the hydrous oxide of iron (2 Fe_2 O_3. 3 aq.);

Hematite, the red oxide of iron (Fe_2 O_3). When rocks contain a good deal of these they are said to be ferruginous.

*The words corniferous and calciferous are, however, usually restricted to particular formations.

Other substances, such as brassy specks of pyrite, shiny scales of mica, etc., do not occur in sufficient abundance to be of importance in naming the samples.

(c) TO RECOGNIZE THESE SUBSTANCES IN DRILL BORINGS.

Carbonates—Place a little of the meal from the boring (not more than the end of a toothpick will carry) on the end of one of the glass slips or on a watch-glass, and add a drop of acid. If limestone is present, the acid will fizz and effervesce promptly and freely; but if there is dolomite or siderite, it will not effervesce freely until heated gently. Do not heat too much, or you may mistake boiling for this effervescence, which is due to the giving off of gas (CO_2). This begins at a lower temperature, and continues much longer after the heat is withdrawn. Add acid until no further effervescence is produced and then dry or evaporate gently. The presence of gypsum may usually be detected by the early appearance, near the margin of the drop, long before the drop is dry, of tufts of needle-like crystals. The pocket lens may be needed to see them. When the drop is completely dry there will be a white coating left, from the amount of which the proportion of soluble matter may be estimated. If there is much iron in the rock it will turn yellow, and then red, as the heat is continued. If the rock was originally yellow or red the iron may have been in the form of limonite; otherwise it was probably a carbonate. A residue that cannot be dissolved, if harsh and gritty, harder than a knife, so that if rubbed between two pieces of glass it leaves fine scratches on them, contains either quartz or chert. Under the lens the quartz can commonly be seen to have the form of translucent rounded colorless grains. The chert is generally opaque, white and angular.

Clay is not gritty; it is cloudy, white or gray, soft and opaque, softer even than gypsum, and settles slowly in water.

Bituminous and *coaly shales* smoke and give off an aromatic odor when strongly heated.

Gypsum and *anhydrite*, being only slightly soluble, remain largely undissolved. To distinguish them apart we must have recourse to the microscope or to chemical tests for water. If the meal furnished by the drill is reasonably coarse we can, by the

aid of the lens, distinguish the micaceous cleavage of gypsum and anhydrite. They are, however, brittle and not flexible like mica. Anhydrite, unlike gypsum, cannot be scratched by the thumb nail.

The *soluble salts* may be recognized by their taste to one who is familiar with them, *e. g.*, salt, saline; epsom ($Mg\ S\ O_4$. 7 aq.) and other magnesian salts, bitter; glauber salt ($Na\ S\ O_4$. 10 aq.), cool.

CHAPTER III.

LOCAL DESCRIPTIONS.

§ 1. (*a*) The records of well-borings which are given herein may be divided into three groups: those already published, those collected and more or less worked up by Mr. C. E. Wright, and those whose collection or working up has been made by this Survey since Mr. Wright's time.

In all cases we give in the text, first the township, then the county, then in the few wells from adjacent states, the state. Next follows the altitude of the place, generally on Mr. Gannett's authority, and intended to give some idea of the elevation above sea level of the mouth of the well. In only two or three cases do we know the altitude of the top of the well more nearly.

Next follows (when known) the name of the well, or the firm or the company for whom it was sunk, then the depth. Then finally we give the authorities for it. When the record of a well has been already published we do not repeat it, unless we intend to use it for comparison, or desire to throw it into more convenient shape, or wish to show into what groups we should divide it.

Of the wells whose records are now, for the first time, published, plates have in most cases been made. We give in them, in parallel columns,—

1. The formations into which I divide the series.
2. The formations into which Mr. Wright divided it, whenever he divided it at all.
3. References to equivalent depths in other wells; *e. g.*, "S. B., 385," means that the beds opposite to which this symbol is placed are equivalent to those encountered at a depth of 385 feet in sinking the well at South Bend, Indiana.
4. The plate representing schematically the succession of the beds.
5. The depths at which samples were taken and also the

depths between which the nature of the rock remained tolerably constant.

6. Either in the same or in separate columns, the drillers' record of what was encountered, and the notes by Wright or myself on the nature of the samples. I have left Wright's notes untouched except where I was certain of inaccuracies, and where the main part of the work is Wright's, or (I often cannot tell which) was derived by him from some one else unknown, my additions are enclosed in parentheses and matters I consider very dubious, in brackets. It is not always easy to distinguish the drillers' log from Mr. Wright's own notes. I have tried to give the reader as much information as I myself possessed.

One thing I should perhaps explain: Mr. Wright, in the diagrams which he correlated, was accustomed to unite the formations into larger divisions or series and refer them to their systems. These columns I have often left out, partly for the sake of compactness, partly because his work, as well as mine, is purely lithological and stratigraphical, and hence lacks validity in attempting to correlate the local formations into the universally applicable series and systems. As he borrowed his names largely from the Ohio Survey, this arrangement of them is his, generally speaking. Of course, therefore, he ran the Devonian down to include what he called Oriskany sandstone, etc.

Often the well-record is so imperfect that, although worth giving, exact divisions of parts of it cannot be given. In this case I have sometimes given the names of the formations without indicating by braces their exact limits.

(*b*) We also give a map of the Lower Peninsula. On this the names of the towns from which we give records are underlined in red. It thus serves as a geographical key to the records. On the same map are irregularly concentric lines, whose use has been explained above. They give a rough geological map of the state and show where it is supposed that the lines of division between the formations would come to the surface, were all the surface soil removed.

They are, as stated in the legend of the map,

1. Line between the base of the Coal Measures (the Parma white sandstone or conglomerate generally), and the top of the Grand Rapids group (generally a limestone).

2. Top of the Marshall sandstone.

3. Bottom of the Marshall sandstone.

4. Bottom of the Richmondville sandstone.

5. Line between the St. Clair bituminous Black shale and the Traverse blue limestone or shale.

6. Line between the Traverse bluish shaly beds and the light Dundee limestones.

7. Line at the bottom of the Dundee limestone, marking the change to dolomite. (N. B. Dolomites burn to a milder lime than genuine limestones.)

8. Line marking the sandstone of Ida and Sylvania.

It will be noticed that the last five lines cross the state line into Ohio much nearer Toledo than Rominger's map of 1876 would make them. This is justified not only by the well-records but by the connecting work of the Ohio geologists.

The transgression of the Subcarboniferous shales into Ohio and Indiana has not hitherto been noticed. This is probably due to two causes. In the first place, the region in question is heavily coated with surface deposits, and shows no outcrops. Furthermore, Winchell ignored the Richmondville sandstone, whose importance seems to have been first appreciated by Wright, and placed the base of the Carboniferous at the bottom of the Marshall group. Now this line, as our map shows, remains within the state.

(*c*) On the map we also indicate by narrow lines the courses of the geological sections which are given in the other plates, and which show, as nearly as we know them, the depths of the different beds of rock and their ups and downs beneath the lines aforesaid. The same signs are used for the different kinds of rocks as in the engravings of the different wells.

Three of these cross-sections run nearly through the center of the basin, viz.: 1. One from Niles to Bay City, running not far from Caseville and Port Austin; 2. From Hillsdale to Bay City and thence up the coast to Alpena; 3. From Detroit to Saginaw, thence extending through Grand Traverse Bay.

The names of places, as for example Port Austin, that do not lie exactly on these cross-sections, I have placed on the nearest cross-section at points where the places would be, if projected directly upon it, but it is obvious that if the rocks were in a mathematically perfect basin, the point of the cross-section which would have the same record as Port Austin would be

found at the intersection of the line of section with a circle through Port Austin having the same center as the basin. And as a matter of fact, I have taken the southeast corner of T. 11 N., R. 1 W., as near enough to the center of the basin (it is probably not far enough west, but I could not tell this until after I had constructed the sections) and have, by circles around it, found the points on any particular line of section corresponding to places off it, and at *these points* laid off the *geological columns* revealed by the borings.

The two methods, direct projection and projection by circles, generally lead to points of projection close together, as I have chosen the sections to run near to as many of the wells as possible. These points of projection are connected by curved arrows.

It will be noticed that the more frequent the well-records are, the more minor inflections there are shown to be in the beds. The question then arises, when there are not enough records shall we put in ideal flexures or unconformities to indicate the fact that there are flexures and unconformities, or shall we sweep the lines along in graceful curves.

Much may be said on both sides, but the latter plan has the advantage that the depth of a bed at a given point, as derived from the section, will in general not be so much in error as if we put in minor bends at random.

(*d*) Now, one use to which these sections may be put is to ascertain what succession of rocks may be expected to be found under any given place. To determine this, describe on the map, about the center of the basin, a circle passing through the point at which it is proposed to sink a well. Suppose, for example, that this is Allegan. This circle will cut the cross-section lines on the map, the Niles-Bay City section (A–B), near Kalamazoo, the Muskegon-Charlotte section (J–K), near Muskegon. Take the point of intersection on the nearest section line, *e. g.*, near Kalamazoo, and find by the scale of the map its distance in miles from the nearest point for which a well-section is given, *i. e.*, Kalamazoo. Then on the profile line of the same cross-section, *i. e.* A–B, plate LXVII, take a point at the same distance horizontally (from Kalamazoo). Draw a vertical line from it. Mark off on this line a distance corresponding to the estimated altitude of the point at which boring is proposed above

lake or sea-level, and the vertical distances from the new point thus found to the various lines which mark the important divisions of the rock column will represent on the same scale as the rest of the figure, the depths at which these divisions ought to be found. If the place, whose underlying rocks, *i. e.*, geological column, are in question, is not much nearer one cross-section than another, it would be better to project as above on the two nearest sections, and find thus two rock columns which will in general differ considerably. The true depths will probably lie between them.

The three other sections, viz.:

4. Niles-Frankfort,

5. Charlotte-Muskegon,

6. Monroe-Port Huron, do not run near the center of the basin and the circular method of projection cannot be applied to them. Places off the cross-section lines are projected directly upon them and either their well-record directly described or a somewhat arbitrary allowance made for their being nearer to or further from the center of the basin, depending on general apparent dip. But after the depth of some one important horizon has been fixed, the distance of the other horizons above and below it are given exactly as in the boring.

Among the more important suggestions brought out by these sections is the possibility of a slight elevation of the strata, or an anticlinal, south of Saginaw, and of other such flexures near Tawas City, south from Hat Point, in Huron county, toward Lake St. Clair, and about Manistee.

§ 2. The references to Rominger and Winchell are to their reports for the Geological Survey of Michigan. Local authorities for information—the officers of the Survey owe many thanks to those who have so courteously and generously assisted them in the interests of science—precede the descriptions of the wells.

ADRIAN, Lenawee County. (Plate I.)

ALBION, Calhoun County. Alt. 943 feet.

Rominger, III, 81.

Total Depth.	Formation.
10 feet	Drift.
281 "	Solid sandrock; drinking water.
	(Marshall sandstone, of Jackson well, 88–373.)
381 "	Blue shales.

ALCONA, Alcona County. Altitude (lake-level 590 feet?).

According to Wright, the (Ohio) Huron or Genesee shales come in here.

ALGONAC, St. Clair County. (Two wells. Plates II and III.)

ALLEGAN, Allegan County. Altitude 708 feet. (Plate IV.)

There was a well bored here in 1887, by a company of which H. H. Pope was president and W. B. Williams, jr., secretary.

Hon. David Stockdale writes: "Three wells were put down here, at a depth of about 1,300 feet, and each time struck oil; but in such small quantities * * * *." Julius C. Ellinger, president of another company, writes: "It took over three months to drill No. 1 well; contractors, Shaler & Thompson, Findlay, Ohio; depth, 1,275 feet. No. 2 was drilled in fourteen days, 1,400 feet 6 inches; No. 3, 1,407 feet, in thirteen days, by Long & Kostetter of Pittsburg, Pennsylvania. No. 1 well would produce, before shooting, about five barrels per day" (not essentially increased by shooting); "we strike considerable salt water in the Brown shale between 1,120 and 1,200 feet, * * *. The last two wells were drilled from 100 to 125 feet below oil sand, in solid lime rock, dry as a bone." The section is appended.

To the kindness of Mr. Ellinger we owe the records and samples from which the cut has been made.

ALMA, Gratiot County. Altitude 797 feet.

Alma Sanitarium Company. Depth 2863 feet.

J. H. Lancashire, M. D., Vice President and Secretary.

Boring begun December, 1889, finished June, 1890.

The sand pump was filled with water from the bottom of the well. This water, emptied into a barrel, showed a temperature of 98° F. This indicates an earth temperature gradient of 1° F. in 54 feet.

The following remarkable analysis confirms what has been suggested on p. 34, as to the predominance in the deep parts of the basin near its center, of bromides that were left in solution after the crystallization of other salts. This analysis is of a mixture of the water from the bottom of the well, with that which comes in at 1053 feet. The water rises five feet above the ground in the well-casing.

New York, May 24, 1894.

"The sample of water marked 'Alma Mineral Water' submitted to us for examination contains in one U. S. gallon* of 231 cubic inches:

Potassium chloride	63.7845	grains.
Sodium chloride	9581.3242	"
Lithium chloride	traces	
Ammonium chloride	43.0859	"
Calcium chloride	6304.2741	"
Magnesium chloride	2256.9909	"
Ferrous chloride	15.4101	"
Sodium bromide	80.8238	"
Sodium iodide	traces	
Potassium sulphate	58.1949	"
Sodium Phosphate	traces	
Alumina	3.9005	"
Silica	0.8324	"
Total	18,408.6213	

C. F. CHANDLER, PH. D.
CHAS. E. PELLEW, E. M."

A set of samples of the formations passed through in sinking the well is preserved at the sanitarium.

"At about 1053 feet we struck a large flow of water, which strongly resembled the Michigan salt wells." This is doubtless the horizon of the Marshall.

"The last 1500 feet was through shale rock the entire distance without striking a drop of water, the shale varying from blue to black." These are the Coldwater and St. Clair shales. "In going through this shale we averaged 25 feet per day" (24 hours). "Our water was struck in limerock, which was so hard that we with difficulty went three feet per day." This corresponds to the cherty Corniferous or Dundee.

ALPENA, Alpena County. Altitude 609 feet. (Plate V.)

1. T. Sterry Hunt (Geological Survey of Canada, 1876, p. 240), quotes Winchell (1874?) that salt was struck at 1,164 feet. I have not found the reference, as there is no paper published by

* As water analyses are variously estimated, it may be worth while to state that
1 U. S. liquid gallon=231 cu. in. or 8. 33888 lbs. Av.=58.372 grains.
1 Imperial " =277.274 cu. in. or 10. lbs. Av.=70.000 "
=very nearly 6-5 of 1 U. S. gallon.
1 Litre=.264179 U. S. liquid gallon.
=.220090 Imperial "
1 Gramme=15.432 grains.

Winchell in 1874, given in the bibliography published in the American Geologist.

2. Rominger, III, 39 (analysis), 40, 63. Two wells, one earlier than 1866; another, close to the bed of Thunder Bay River. The record of the latter is given in Plate V.

3. A third well was sunk in 1891. Depth, 1,267 feet.

Hon. E. K. Potter. The record is not as complete as that of No. 2.

ANN ARBOR, Washtenaw County. Altitude of M. C. R. R. track, according to Gannett, 771 feet. According to Winchell, the altitude of the same point is 764 feet; of the Observatory, 909 feet; of the University grounds, 867 feet; of the top of the boring given below, 781 feet. Depth, 770 feet.

"In the south part of Washtenaw County and in the northwestern corner of Monroe County, in well borings, the black shales are found usually not more than about 100 feet below the surface. Frequently a stream of * * * gas escapes * * *."

Rominger, III, 68,* 92.

Rominger's record is as follows:

Lane.	Rominger.	Thickness.	Formation.
		1-155 feet.	
Coldwater	Cuyahoga	155–305	Blue arenaceous shales with seams of fine-grained sandstones.
		305–333	Black bituminous shales, gas, and drops of oil.
Richmondville	Berea	333–425	Coarse, gray sandstone, with a brine of Sp. Wt. 1. 142, 19% Na Cl by evaporation.
St. Clair	Bedford	425–525	Blue shales with subordinate sandstone layers and seams of pyrite.
	Cleveland	525–610	Black shales, very bituminous, with iron pyrite.
	Erie	610–632	Dark blue, arenaceous shales, with iron pyrite and traces of fossils.
	Ohio	632–700	Black bituminous shales, with iron pyrite.
Traverse	Helderberg	700–770	Limestone, bluish colored, with flint.

*p. 68. Black shales struck at 525, their thickness there being 85 feet.

Winchell, Geology of Washtenaw County, in the History of Washtenaw County, 1881. Boring on Main street, Court House square.

Winchell's record is as follows:

ARTESIAN BORING, ANN ARBOR, 1871.

At depth of	Thickness.	Thickness of Group.	Descriptions.
			DRIFT—
0	30		Soil, gravel, etc.
30	101		Clay, bluish and adhesive, with alternating seams of quicksand.
65			Bottom of shaft and beginning of boring.
131	½		Quicksand, rendering tubing necessary.
131½	28½		Compactly bedded, shale-like materials. Tubed to here.
160	4	164	Partially cemented sand. Drove two more lengths of pipe.
			MICHIGAN SALT GROUP—
164	51		Shale, light bluish, varying to dark gray, not effervescing with acid, fine, laminated, with minute disseminated scales of white mica. Some portions—apparently thin seams—buffish, rather hard, very slightly effervescing with acid. Drove four feet more of pipe to this shale. Water from shaft was shut off. A little water continued to appear in the pipe.
215	½		Crevice. Fresh water arose immediately to within 25 or 30 feet of the surface.
215½	104½		Shale, as above the crevice.
320	6		A cavity from which issued inflammable gas, and a little black oil.
326	4	166	Black shale, not effervescing with acids.
			MARSHALL GROUP—
330	62		Sandstone, dun, earthy, porous, actively effervescing with acid. Contains brine. At a depth of three feet in it, a sample of brine stands 50° salometer.
366	26		Same rock continuing, but more distinctly arenaceous.
392	35		Fine buffish, calciferous or magnesian sandrock—about one-fourth dissolving in sulphuric acid.
		123	Brine here 64° salometer.

At depth of	Thickness.	Thickness of Group.	Descriptions.
			HURON GROUP—
427	13		Shale, argillaceous, bluish. The sand pump brings, with chips of shale, much sand.
430			Shale continuing. Water lowers to 40 ft. from surface. Brine here 68° salometer.
433			Shale continuing. Sand pump brings up no sediment.
440	29		Silicious shale, excessively fine, compact, bluish-gray, accompanied by gas, which caused an overflow of water at the top of the well. Water afterward subsided, but some gas continued to escape.
453			Same continuing. When lighted paper is thrown down, numerous detonations occur in the well.
469	251	293	Silico-argillaceous shale, not effervescing. Some beds of black bituminous shale.
			HAMILTON—CORNIFEROUS
720			Limestone (with ferruginous specks) apparently somewhat cherty.
745			Chips of earthy magnesian limestone with some sand.
755			Chips quite sandy, with magnesian limestone, iron and clay. Work discontinued.

An analysis of the solid residue was made by Mr. J. R. Jones, with the following result:

Percentage solid matter in brine 17.48

	Per cent.
Iron (in the residue after evaporation)	2.506
Magnesium chloride	3.976
Calcium chloride	14.022
Sodium chloride (common salt)	79.496
Total	100.000

BANKS (West Bay City), Bay County, two miles north of Bay City. Altitude, 592 feet (?).

Rominger, III, 200.

Wells.	Total Depth. Rominger.
Moore & Smith	830 feet.
Long & Bradfield	800 "
Taylor & Moulthop	840 "
Keystone Lumber and Salt Company	980 "
Bangor Salt Manufacturing Company; 95° brine	774 "

The above wells are in the lower salt rock=Napoleon; *i. e.*, the Marshall sandstone is the source of the brines.

Battle Creek, Calhoun County. Altitude, 819 feet. Depth, 440 feet.

Rominger, III, 83.

Total Depth.	Thickness.	Formation.
	70 feet.	Drift.
113 feet.	43 "	Sandrock.
116 "	3 "	Cavity; stream of water (compare a similar phenomenon at Marshall).
442 "	326 "	Blue shales.
	440 "	

Bay City, Bay County. Altitude, 592 feet. (Plate VI.)

C. E. Wright. See also Winchell, 1860, 154; also Rominger, III, 107, 182, 200.

Beside the deep well which is engraved,* there are a large number of shallower wells down to the brine, *e. g.*,

*This well is reported to have been driven further than is shown by the engraved record.—down to 3,000 feet. Wright quotes Zacharias Mason as saying that at 2,900 feet it was in rock the same as that at 1,300 feet in Morley's well (Plate XXXVII), one-half mile north of Marine City.

Wells.	Total depth, through sandrock, either Parma (635 ft.) or Marshall (920 ft.) of main well.
Geo. F. Williams & Bro.	835 feet.
Wiley Bros.	765 "
Whittlesey	725 "
E. F. Gould	715 "
Sanborn & Bliss	750–765 "
C. L. Grant & Company, in Carrollton	770 "
Hamilton & McClure	860 "
Batchelor & Whitney	875 "
G. C. Meyers	940 "
Hay, Buttman & Company	1040 "
Bradley & Sons	1040 "
Eddy, Avery & Eddy	1040 "
F. E. Bradley	1010 "
Lockwood (Opp. side of river)	860 "
Sage (Opp. side of river, W. Bay City)	995 "
E. Hall	940 "
Eddy Bros.	910 "
McEwan Bros.	873 "
Rouse	853 "
J. R. Hall	830 "
Gilmore (Brine 65°, upper salt-bearing sand rock)	505 "

(These records are taken from Wright's notes, and the wells are probably not all exactly in Bay City.) In some of the Bay City wells, a gypsum horizon occurs at 700 feet.

T. Sterry Hunt quotes from the Inter-Ocean, April 1877, the report of a bed of rock salt 115 feet thick at 2085 feet. This probably refers to the brine-bearing Berea sandstone.

BENTON HARBOR, Berrien County. (Plate VII.)

BLACKMAR, Taymouth Township, Saginaw County. Altitude 613 feet.

Mr. Blackmar. Depth 1764 feet (but the column adds up only 1677 feet).

Rominger, III, 96, 184.

References by Lane.	Total depth.	Thickness.	Formation.
	1-90 feet.	90 feet.	Drift.
Bay City, 920	360 "	270 "	Shale.
Flint, 170-278	450 "	90 "	Coarse sandrock.
	495 "	45 "	Blue shales.
	695 "	200 "	Red shales.
Flint, 1200	1545 "	850 "	Gray arenaceous shales.
Bay City, 2300, Berea (?)	1655 "	110 "	Sandstone, strong brine at 1675 feet.
East Tawas, 905 (?)	1675 "	20 "	Gray shale.
Caseville, 1750	1677 "	2 "	Limestone.

Branch Station (near Coldwater, *q. v.*), Branch County. Altitude 927–983 feet.

Dr. Bennett. Depth 447 feet.

Rominger, III, 87.

Thickness.	Formation.
26 feet.	Drift.
26-203 "	Soft, blue shales.
203-216 "	Hard, blue shales, containing crinoid stems and Chonetes.
216-447 "	Below this, shale with sandy and calcareous streaks.

Carrollton, Saginaw County (just north of Saginaw). Altitude 590 feet (?). Depth 743-800 feet.

Rominger, III, 200.

C. E. Wright.

Wells.	Total depth acc. to Rominger.	Total depth through the sandrock acc. to Wright.
H. B. Allen	800 feet.	
E. F. Gould	800 "	715 feet.
T. Jerome & Co.	746 "	735 "
E. Litchfield	743 "	
H. Ballentine & Co.	763 "	
Saginaw Valley Salt Company	780 "	
H. P. Lyon & Co.		
C. L. Grant & Co.		770 "

CASEVILLE, Huron County. Altitude 594 feet.

(1) Frank Crawford. Depth 1760 feet (given variously 1750, 1760 and 1770).

(2) Pigeon River Furnace Company.

Rominger, III, 94, 184, 201.

C. E. Wright.

Surface, Subcarboniferous limestone. Rominger, III, 103, and A. Winchell, 1860.

Depths.	Formation.
1-900 feet.	Principally blue, more rarely red, shales.
850-950 "	White sandrock; large body of strong brine. Sandstone. Wright.
1650-1770 "	Sandstone. Wright.

CHARLOTTE, Eaton County. (Plate VIII.)

CHEBOYGAN, Cheboygan County. Altitude 604 feet.

J. J. Mason. Depth 700 feet.

C. E. Wright.

"Caved badly, conglomerate in part, much quartz, flint and boulders, a strong flow of fresh water, no brine."

See also paper by N. H. Winchell, 1871, on the economic geology of that region.

CHESTER, Eaton County. Altitude 883 feet.

Rominger, III, 131.

Depths.	Formation.
1–8 feet.	Drift.
8–16 "	Hard, black shale with thin coal.
16–23 "	Whitish fine-grained sandrock.
23–53 "	Whitish plastic fire clay.
53–83 "	Black shale with pyrite.
	White fire clay with hard ferruginous bands.

CLIFFORD, Lapeer County. (Plate IX.)

COLDWATER, Branch County. (X.)

CONSTANTINE, St. Joseph County. (Plate XI.)

CORUNNA, Shiawassee County. Altitude 776 feet. (Plate XII.)

No. 1 shaft has a depth of 80 feet. Rominger (III, 138) gives the following section from the oblique drift:

Total depth.	Thickness.	Formation.
	9 feet.	Drift (surface deposits).
	30 "	Shale, dark to black.
	4 "	Sandstone.
	6 "	Black, slaty shales, containing Lingula and Discina and compressed lamellibranchs.
49–50 feet.	1 "	Coal.
	4 "	Fire-clay.*
	8 "	Black, slaty shales, as above.
62–66 "	3 to 4 "	Coal.
	4 "	Fire-clay.*
	4 "	Black shales.
80 "		Arenaceous shales.

* Fire-clay seams are usually arenaceous and contain Stigmaria. The shales contain lenticular kidney iron ore.

No. 2. Engineering and Mining Journal, Nov. 5, 1881. New shaft at Corunna has entered five feet and six inches of coal at seventy-five feet.

CORUNNA, Ontario, on the St. Clair River. Underneath it are 213 feet of St. Clair black shales. See Brumell, Bull. Geol. Soc. Am., 1893, IV, 227.

COURTWRIGHT, Ontario. (Plate XIII.)

DELPHI, Indiana. (Plate XIV.)

DETROIT, Wayne County. (Plate XV.)

DOWAGIAC, Cass County. (Plate XVI.)

The driller's record as given by Mr. Farr in a note to C. E. Wright, of Nov. 21, 1887, is slightly different from that of plate, which is constructed from the samples, viz.:

Total depths.	Thickness.	Formation.
0-202 feet.	202 feet.	Drift.
202-297 "	95 "	Blue slate.
297-309 "	12 "	Red slate.
309-358 "	49 "	Blue slate.
358-462 "	104 "	(274? or 106?) Hard rock.
462-582 "	120 "	Blue slate.
582-687 "	105 "	Black shale.
687-782 "	95 "	Brown shale.
782-819 "	37 "	Gray shale.
819-893 "	74 "	Lime with mineral water.
893-969 "	76 "	Lime (I think?).
969-994 "	25 "	Brown stone.
994-1009 "	15 "	Yellow stone.
1009-1052 "	43 "	Limestone.
1052-1069 "	17 "	Yellow stone.
1900 "	----------	Well is now at 1900 feet, with no prospects of gas.

EAST SAGINAW, Saginaw County. Altitude 588 feet.

G. A. Lathrop, M. D. East Saginaw Salt Manufacturing Co.

Winchell, 1860, 152, 153.

Rominger, III, 94, 181, 200.

Groups.	Total depth.	Formation.	Strength of brine, Rom., p. 181, at
JACKSON COAL GROUP			
	92 feet.	Drift	90 ft. 1°
Upper sandstone?	92-170 "	Sandstone	102 ft. 2°
	170-196 "	Dark shale.	
	196-210 "	Light shale	211 ft. 10°
	210-233 "	Sandstone with coal seams	212 ft. 14°
	233-246 "	Shale.	
	246-256 "	Sand with coal seams.	
	256-292 "	Blue shale.	
Parma sandstone?	292-398 "	White sandstone.	

Groups.	Total depth.	Formation.	Strength of brine. Rom., p. 181. at
GD. RAPIDS GROUP:			
	398-403 feet		
	403-408 "		
	408-412 "		
Subcarboniferous	412-413 "		
	413-419 "		
	419-420 "	Alternate limestone and sandstone.	
	420-428 "		
	428-429 "		
	429-434 "		
	434-435 "		
	435-447 "		
	447-449 "		
	449-462 "	Limestone, sandstone and shale mixed.	
	462-465 "		
	465-476 "		
	476-514 "		487 ft. 26°
	514-516 "		516 ft. 40°
	516-530 "	Alternate shale and sandstone	
	530-532 "		531 ft. 44°
	532-535 "		
	535-536 "		
	536-540 "		
	540-558 ft.	Arenaceous shale.	
	558-566 "	Sandstone	559 ft. 60°
	566-568 "		
	568-583 "	Alternate dark shales and sandstone	569 ft. 64°
	583-588 "		
	588-591 "		
	591-592 "		
	592-595 "	Gray, coarse sandstone	
	595-602 "	Dark shales.	
	602-607 "	Sandstone and shale	606 ft. 86° (Rom., p. 95, 612 ft. 90°)
	607-612 "		
	612-617 "	White sandrock	
	617-623 "	Dark shales	
	623-624 "	Cherty calcareous rock	
	624-626 "	Dark shales	
	626-634 "	Sandrock and shales	
	634-733 "		
Marshall? Bay City 800?	733-797 "	Sandstone	636 ft. 90° (Rom., p. 96, 733 ft. 94°)
	797-800 "	Bright red shales.	

East Tawas, Iosco County. Altitude about 590 feet.

(1) Grant and Company. Depth 905 feet.

Rominger, III, 78-9, 184, 201.

The different figures given for thickness add up 883 feet instead of 905 feet as given by Rominger. According to Wright, from 800 feet to 900 feet is sandstone.

Thickness.	Formation.
1–50 feet.	Surface drift.
50–170 "	Sandstones.
170–338 "	Shales.
338–378 "	Sandstone.
378–458 "	Shale and sandstone.
458–508 "	Mainly shale.
508–514 "	Shale, first indications of brine.
514–678 "	Shale, white and hard.
678–873 "	Sandstone, gray; abundant supply of strong brine, 85°.
873–883 "	Blue shale.

(2) Weekes Bros. Depth 835 feet.

Eaton Rapids, Eaton County. Altitude 876 feet.

Mr. Frost.

Rominger, III, 130.

Depth.	Formation.
20 feet.	Drift.
20–120 "	Alternating shale and sandrock.
120 "	Coal.

Elkhart, Indiana. (Plate XVII.)

Essexville, Bay County (near Bay City). Altitude about the same as that of Bay City, 592 feet.

C. E. Wright.

Depth.	Formation.
670 feet	To sandstone; brine.
755 "	Through sandstone; brine.

Flint, Genesee County. Altitude 715 feet.

Dr. Clark. Depth 1200 feet.

Rominger, III, 97. Several borings with no trace of Subcarboniferous limestone, *e. g.*

Reference.	Total depth.	Thickness.	Formation.
	68 feet.	----------	Drift.
	68-135 "	67 feet.	Sandstone.
	135-170 "	35 "	Shales and sandstone, with seams of coal.
Blackmar, 450 (?)	170-278 "	108 "	Sandstone; at 260 feet strong stream of sweet water.
Blackmar, 1545 (?)	278-1200 "		Alternations of shale and sandstone; in the lower part strong brine.

Florence, Saginaw County. Altitude (?).

(1) Chicago Salt Company. Depth 800 feet.

(2) Shaw and Williams.

Rominger, III, 200.

Forestville, Sanilac County. Altitude about 600 feet.

C. E. Wright. Depth 505 feet.

"It is 465 feet to the sandstone, which is forty feet thick."

FRANKFORT, Benzie County. (Plate XVIII.)

C. E. Wright. D. B. Butler.

There were two wells sunk, one—the first—is 1800 feet deep. Of that Mr. Wright collected the record so far as given in the plate. The water interfered so much with further boring that this well was given up, and a second one was begun about 500 feet to the southwest. The latter is 2200 feet deep. When the well was about 1800 feet deep the salinometer gave 20%. This corresponds evidently to the Stronach and Manistee salt horizon. See cross-section C–H from Niles to Frankfort. This well was continued to 2200 feet, but with lessening per cent of salt, until it gave out altogether. It doubtless pierced the Niagara.

The appended analysis of the water, which has quite a reputation as a mineral water, is reported. The well has a daily flow of over 8000 barrels; temperature, 58° F. As the mean annual temperature for Frankfort should be, according to Winchell's researches, between 44° and 45° F., this would give an increase in the earth's temperature of 1° F. for each 100 feet of depth. The flow begins at a depth of about 1400 feet, at a geological horizon near that of Ypsilanti, whose water it resembles.

"The water contains in the Imperial gallon of 10 lbs. 240.32 grains of solid matter, consisting of:

Sulphate of lime	85.40	grains.
Sulphate of magnesia	77.00	"
Sulphate of soda	40.60	"
Chloride of sodium	28.60	"
Chloride of potassium, traces		"
Carbonate of magnesia	6.30	"
Oxide of iron	1.26	"
Soluble silica	1.16	"
One gallon. Total	240.32	"

It also contains 44½ cubic inches of H_2S in solution in each gallon.

R. C. KEDZIE,
Michigan State Agricultural College."

FRUITPORT (near Grand Haven), Ottawa County. Altitude 596 feet (?).

(1) "Iron Magnetic Springs." June 2, 1871.

Thomas M. Nelson, Chicago. See also Peale, Bull. U. S. Geol. Survey, No. 32, p. 147.

Analysis by C. G. Wheeler.

Section.		Analysis.	
Surface sand	30 feet.	Temp. 48° F.	
Clay	140 "	Na_2CO_3	6.5156
Hardpan	9 "	$Ca\,CO_3$	5.1100
Blue sandrock	24 "	$Fe\,CO_3$	7.5600
Blue shale	5 "	$Mg\,CO_3$	4.1511
Marshall (?) sandrock	41 "	$Mn\,CO_3$	0.1050
Blue shale	6 "		23.4417
Total	255 feet.		
		K Cl	0.4312
		$Ca\,Cl_2$	111.1110
		Na Cl	464.0319
		$Mg\,Cl_2$	46.8072
		$Mg\,Br_2$ (?)	0.7666
		Na_2SO_4	45.9960
		SiO_2, Al_2O_3	10.6050
			679.7489

(2) Spring Lake Iron Company.

(3) Magnetic Mineral Spring Co.

GOSHEN, Indiana. (Plate XIX.)

GODERICH, east shore of Lake Huron, Ontario, Canada. Altitude 780 feet.

Henry Atrill, Esq., New York City. Depth, 1517 feet.

T. Sterry Hunt. Trans. Am. I. Min. Eng., V, 538,—Geol. Survey of Canada, 1876-1877, p. 221-243,* with plate.

Am. Geol. R. R. Guide, p. 64.

Thickness. Equivalent depth.	Formation.
78 ft. 9 in.	Drift.
Monroe { 278 ft. 3 in.	Dolomite with thin limestone layers.
100–300 { 276 ft.	Limestone with corals, chert and dolomite beds (colony of Upper Helderberg (?) L.).
243 ft.	Dolomite with seams of gypsum.
	The rest, marls with heavy beds of rocksalt and some anhydrite and dolomite.

GRAND HAVEN, Ottawa County. Altitude, 594 feet.

W. C. Sheldon.

T. S. Nelson. (See Fruitport.)

GRAND LEDGE, Eaton County. Altitude 860 feet.

Rominger, III, 131–133.

GRAND RAPIDS, Kent County. Altitude 605–639 feet. (1) and (2) (Plates XX and XXI.)

Winchell, 1860, p. 144–150, 153.

Rominger, III, 110, 180.

C. E. Wright.

One well was bored a number of years ago 700–800 feet deep, The Marshall sandstone is struck at 350 feet and is 100 feet thick.

(3) Beyrich's brewery, depth 236 feet.

(4) Powell's block, 204 feet.

* p. 242. At Clinton, 13 miles southeast from Goderich, it was 1180 feet, 216 feet deeper than at Goderich, to reach rocksalt.

p. 241. Goderich was supposed to stand on the boundary line between Upper and Lower Helderberg.

The cherty limestone (276 feet) appears to be Upper Helderberg.—contains Favosites Winchelli, Favosit e Emmonsi, Acervularia and Diphyphyllum.

Grindstone City, Huron County. (Shore of Lake Huron.) Altitude 590 feet (?).

Worthington & Son. Depth 1080 feet.

C. E. Wright.

Thickness — 1010 1080 feet. Formation — Sandstone.

Hillsdale, Hillsdale County. Altitude 1095 feet.

Rominger, III, 81.

Two wells bored in the court house square.

(1) Thirteen hundred and fifty feet.

(2) Fifteen hundred and fifty feet, by hearsay as follows:

Thickness.	Formation.
(?) ft.	Drift.
20 "	Soft laminated micaceous sandrock.
1120 "	Mainly bluish shales with arenaceous seams and harder, probably calcareous ledges. The color of the shales became dark, bituminous, in the lower part.
1120–1350(?) "	Hard red rock with much iron pyrite, and strongly saline water.
1350–1400(?) "	Fifty feet of white limestone.
1400(?)–1550 "	Soft calcareous rock to end.

Howell, Livingston County. Altitude (?).

Newspaper clipping (some Detroit daily).

"Howell, Mich., July 22.—(Special.)—While workmen were digging a well at Walter Papsworth's residence, in the eastern part of the village, this morning a terrific roaring was heard and stones and dirt were blown 100 feet into the air. Natural gas had been struck. The flow was lighted, and a flame as large as a barrel ascended to a height of 30 feet. To-night the tap will be lighted again, and later a meeting will be held to determine what to do with the discovery."

L. C. Smith, Secretary Board of Water Commissioners, private letter Feb. 15, 1893:

"Many years ago in boring near a tract of low, marsh ground, a pocket of inflammable gas was struck which burned for some time. * * * * no more was done about it."

IMLAY CITY, Lapeer County. (Plate XXII.)

IONIA, Ionia County. Altitude 659 feet.

Mr. Blanchard. Depth 450 feet.

Rominger, III, 134. "At 300 feet below the surface a copious stream of sweet water."

ITHACA, Gratiot County. Altitude (?).

Record in the Gratiot Journal, Ithaca, April 14, 1893.

"We give below the complete record of the new well as to the thickness and kind of strata through which the drill passes. The last 86 feet of sandstone will give, it is thought, an abundance of water."

Comparisons.	Formation.	Total depth.	"Record of the new well."
	Quaternary..	10 ft.	10 feet surface clay.
		10-80 "	70 feet blue clay, stony.
		80-118 "	38 feet hardpan.
		118-119 "	1 foot gravel.
		119-149 "	30 feet hardpan.
		149-151 "	2 feet of gravel. Considerable water.
		151-191 "	40 feet hardpan.
		191-195 "	4 feet gravel.
		195-201 "	6 feet blue clay.
		201-211 "	10 feet hardpan.
		211-213 "	2 feet gravel.
		213-273 "	60 feet red clay.
		273-277 "	4 feet hardpan.
		277-302 "	25 feet white clay.
		302-310 "	8 feet blue clay.
		310-320 "	10 feet hardpan. Very hard.
		320-325 "	5 feet gravel.
		325-330 "	5 feet hardpan.

Comparisons.	Formation.	Total depth.	"Record of the new well."
	Woodville (?) sandstone	330-332 ft.	2 feet gray sandstone. Very hard. Bottom of eight-inch casing.
		332-336 "	4 feet gray sandstone.
		336-339 "	3 feet fireclay.
		339-343 "	4 feet red sandstone.
		343-345 "	2 feet red shale.
		345-349 "	4 feet blue shale.
		------ -----	Bottom of seven-inch casing, with two 16 foot lengths, standing up into eight-inch pipe, 15 feet bagged and swedged out on top. Bottom of this casing is 349 feet by measurement.
	Jackson Coal Group	349-355 "	6 feet blue shale.
		355-357 "	2 feet limerock.
		357-362 "	5 feet sandstone.
		362-367 "	5 feet blue shale.
		367-368 "	1 foot dark lime.
		368-383 "	15 feet white shale.
		383-399 "	16 feet black shale.
		399-414 "	15 feet light shale.
		414-434 "	20 feet blue shale.
		434-440 "	6 feet dark lime.
		440-462 "	22 feet light shale.
		462-470 "	8 feet dark lime.
		470-478 "	8 feet sandrock.
		478-480 "	2 feet dark lime.
		480-482 "	8 feet sandrock.
		482-490 "	2 feet light shale.
		490-515 "	25 feet sandrock.
		515-525 "	10 feet light shale.
Ionia, 300 Owosso, 301-404 Corunna, 300-431	Parma	525-611 "	86 feet light sandstone.
		611-613 "	2 feet light shale.
Total depth of well		613 feet.	

It is possible that some of the "lime" might prove to be black band iron ore.

JACKSON, Jackson County. Altitude 928 feet. (Plates XXIII XXV.)

Rominger, III, 122-127.

Winchell, 1860, p. 151, 154.

KALAMAZOO, Kalamazoo County. (Plate XXVI.)

KAWKAWLIN, Bay County. Altitude 596 feet.

Two wells. Depths 810 and 1,133 feet.

Rominger, III, 96, 107.

Thickness.	Formation.
About 100 feet	Drift.
About 100-400 "	Shale and sandrock with coal seams.
About 400-500 "	Gypsum at 400 feet. Limestone and gypsiferous shales.
About 700-800 "	Sandstone with strong brine.
About 800-1133 "	Red shales.

KINGSTONE'S MILLS, Lambton County, Ontario.

See Brumell, Bull. Geol. Soc. Am., 1893, Vol. IV. p. 228.

Hunt, Geology of Canada, 1863, p. 362.

KINGSVILLE, Ontario.

Large gas well reported in Eng. and Min. J., February 9, 1889, owned by Detroit capitalists, and less than 25 miles from Detroit.

See Brumell, Bull. Geol. Soc. Am., 1893, Vol. IV, pp. 231, 238.

LANSING, Ingham County. Altitude 840 feet.

Rominger, III, 117, 118. Of borings made, only the shallowest recorded: (1) At the Reform School. Depth 506 feet.

(2) In the yard of the Lansing Hotel. Depth 740 feet.

(3) Lansing Magnetic well. Depth 1,400 feet. (Peale, Bull. U. S. G. S., No. 32, p. 145). Temperature of water 58°.5 F.; flowing 60 (?) gallons per hour, saline; analysis, p. 148; temperature gradient something less than 190 feet to 1° F.

(4) At the water works are wells showing 20 feet oxidized sand, 16 feet coarser stuff, then rock.

LONDON, Monroe County.

Artesian boring mentioned by Winchell, in 1873, as having reached the Niagara limestone.

Cf. also the boring on Macon Creek, Rominger, III, 27.

LUDINGTON, Mason County. (Plates XXVII–XXIX.)

MANISTEE, Manistee County. Altitude 604 feet. (Plates XXX–XXXII.)

Wells in this neighborhood are those of

	Date.	Depth.
Stronach Lumber Company, at the head of the lake. See Stronach		1970 feet.
Lewis Sands (Manistee Salt Well?); No. 1		2012 "
Canfield (J.) and Wheeler (E. D.) No. 2	Sept., 1883	1947 "
John Canfield; next south of Peters' well		
Davies, Blacker & Co.		
Engleman and Kitzinger; on a little lake 1½ miles from Lake Michigan	Mar., 1883	
R. G. Peters; according to the Engineering and Mining Journal, June 13, 1885, a bed of solid salt, 34 feet thick, was struck at a depth of 2027 feet: No. 3.		
Wheeler, Magill & Co.	Mar., 1885	2026½ "
Rietz Bros.; west side of lake, going north	Feb., 1882	

MARENGO, Calhoun County. Altitude 921 feet.

Rominger, III, 82.

Thickness.	Formation.
1–60 feet	Drift.
60–260 "	Sandrock. (Marshall sandstone. L.)
260–460 "	Shales.

MARINE CITY, St. Clair County, not elevated much above lake level, *i. e.*, altitude about 600 feet. (Plates XXXIII–XXXIX.)

There have been very many wells sunk here, of which that of Lester & Roberts (No. 1) (D. Lester and W. S. Roberts) may be taken as typical. From this well the Geological Survey has a complete set of samples.

Other wells are those of

(No. 2) Baird Brothers,

(No. 3) Curtis & Lester (Toledo Salt Company, C. F. Curtis, W. S. Brainerd, D. Lester),

(4) National Salt Company, with samples,

(5) W. B. Morley, with samples,

(6) Dr. O. W. Owen, with samples,

J. A. Wonsey & Son,

H. C. Wonsey (only to the solid rock—yielding gas),

Antoine Halin (only to the solid rock—yielding gas),

Crockett McElroy (according to the E. and M. J., May 12, 1883, quoting an elaborate account in the Detroit Evening News, well begun over a year ago; at a depth of 1633 feet, struck a deposit of rock salt which the bore hole penetrated 115 feet without passing through; Compare the Baird Brothers' well).

MARSHALL, Calhoun County. Altitude 893 feet.

Rominger, III, 83.

Thickness.	Formation.
70 feet	Drift.
70–113 "	Sandrock.
113–116 "	Cavity; copious stream of water.
116–440 "	Blue shales.

MARYSVILLE, St. Clair County. Four and a half miles south of Port Huron, half a mile west of St. Clair River. Altitude about 600 feet. Church & Company. (Plate XL.)

James Geek struck gas when sinking a shallow well. See Plate XL.

MELBOURNE, Saginaw County.

W. R. Burt & Co. Depth 950 feet.

Rominger, III, 201.

MERIDIAN, Ingham County. Depth 52½ feet.

Rominger, III, 135 (boring four miles west of Williamston, close to the river).

MICHIGAN CITY, Laporte County, Indiana. Altitude 603 feet.

Indiana State Prison.

Rominger, III, 37.

Referred to sea level.	Total depth.	Formation.
603 feet ...	1–170 feet.	Drift.
433 " ...	170–246 "	Ohio black shale.
357 " ...	246+ "	Limestone of the Helderberg.

MIDLAND, Midland County. Altitude 608 feet.

C. E. Wright; John Larkin.

Notes on a map of C. E. Wright, to the effect that from 1200–1300 feet the formation is sandstone.

Well No. 1, 300 feet south of S. W. cor. Sec. 16, T. 14 N., R. 2 E., on bank of Tittabawassee River. Altitude 608 feet.

Eighteen to twenty-five feet above the water of Saginaw Bay and about on a level with the railroad track.

Begun in September, 1878; finished in 1879, for Larkin & Patrick (John Larkin, Wm. Patrick). John Mason, contractor, East Saginaw. Depth 1300–1325 feet.

	Depth.	Thickness.	Record by John Larkin, Esq.
	1-30 ft.	30 ft.	Sand, boulders and loose earth.
	100 "	70 "	Very hard red and white clay.
Kawkawlin, 100-400		5-6 "	Struck shale, and underneath it soft coal; several bushels taken out. Mostly lime rock. Very hard.
Bay City, 585.			
Kawkawlin, 900	800-820 "	15-20 "	Sand rock; brine, 65%. Hard lime rock.
Bay City, 920.			
Kawkawlin, 800?	At 1280 "	20-25 "	Salty sand rock. Brine 115°, *i. e.*, 65° to 75° salt brine, and bromides, etc., for balance.*

* This would mean Sp. Gr. about 1. 2395 and about 17% to 18% salt and somewhat less of the other matters. Bromine is made in large quantities from the refuse water after the salt water is taken out.

The first two wells sunk at Midland, to which the above description applies, were bored by Larkin and Patrick. Two others were sunk, in 1892, by H. W. Daw.

MILAN, Washtenaw County. Farm of Mr. Kinear on Saline River, Monroe County. Altitude about 700 feet.

Rominger, III, 68.

Well was bored with an auger 108 feet through drift, and struck the shales and a seam of gas.

MILWAUKEE, Milwaukee County, Wisconsin. Altitude 584 feet.

Geological Survey of Wisconsin, II, 390–394.

Lower Helderberg barely present as a thin edge; also at Wauwatosa and at Fredonia, Osaukee County (?). Altitude 788 feet.

MONROE, Monroe County. (Plate XLI.)

Rominger, III, 30–31. [No gypsiferous shales underlie Monroe] * * * "for several hundred feet downward limestones

of dolomitic character alternately follow each other." He gives some account of two wells. Samples of well No. 3, show noteworthy quantities of gypsum underneath Monroe.

(1) Court House Square. Depth 140 feet.
(2) Received from Judge Christiancy. Depth 300 feet.
(3) See Plate.

Mt. Clemens, Macomb County. Altitude 612–617 feet. (Plate XLII.)

Authority, T. M. Crocker, Esq.

There have been three wells sunk here, the first over twenty years ago (*i. e.*, before 1872). The second well is more recent, is within a few feet of the first and owned by the same proprietors. The driller's record is given. The third was put down in June–July, 1892. Of this the Survey has some samples, and an engraving has been made. The owner is Mr. Carsons (Coursin?) and the driller Mr. Nims. The surface of the ground where the well is located is a little higher than at the other wells, is about twenty-five feet above the surface of Lake St. Clair and is very nearly on a level with the railroad track. It is not on any government section, but on claim No. 141.

The following is an analysis by S. P. Duffield, in grains per imperial gallon:

$NaCl$	11,900.00
KCl	——
$MgCl_2$	648.48
$CaCl_2$	934.50
$MgCO_3$	.70
$CaCO_3$	.98
$FeCO_3$	5.60
MgI_2	.07
$MgBr_2$	6.37
SiO_2	27.60
Al_2O_3	29.47
$CaSO_4$	100.335
	13,654.105

Mt. Clemens. No. 2.
Driller's "log."

References.	Thickness.	Formation.
	1-102 ft.	Surface.
Royal Oak 105, 164	---	"Bed rock was reached at a depth of 102 feet."
	102-400 "	"Limestone with an occasional shell."
	400-430 "	"Black slate."
Royal Oak 230, 305.		
Royal Oak 520	430-560 "	"Limestone returned, with an occasional shell and strata of slate."
Royal Oak 548		At 560 feet "Sulphur water was first struck."
Royal Oak 836	560-850 "	"Close, white sand" (probably dolomite ?), "uninterrupted."
Royal Oak 836–1305	850-890 "	"Richest slate" (? *i. e.*, plaster, anhydrite or gypsum marl).
Cf. Algonac 1130–1200	890-1000 "	"White sand," "again, interrupted by an occasional stratum of slate."
	1000-1010 "	"Salt vein, having a thickness of about ten feet."
	1010-1050 "	"Followed again by sand."
	1050-1090 "	"Dark slate."
	1090-1244 "	"Sand" (dolomite?), "with now and then a shell and strata of light slate to total depth."

MUSKEGON, Muskegon County. (Plate XLIII.)

Rominger, III, 84, 85, 94. Several borings.

(1) Mr. Whitney. Depth 1230 feet; register to 657 feet.

(2) Probably the same as that recorded by Wright, although the figures vary slightly. The salt water at 1250 feet (Rominger, III, 94) may mark the Berea sandstone.

NEWBERG (near Cleveland), Cuyahoga County, Ohio. Altitude 813 to 748.

Cleveland Rolling Mill Company. Depth 3000 feet.

Geological Survey of Ohio, Vol. VI, p. 352–355.

Epoch acc. to Orton.	Thickness	Formation.
	40- ft.	Drift, sand, clay and gravel.
Ohio shale	40-1350 "	Shale, changing in color.
100 ft. Upper Helderberg	1350-1660 "	Limestone, solid (in part Upper Helderberg).
500 ft. Lower Helderberg	1660-1700 "	Sand (first salt-water vein Sylvania).
	1700-1990 "	Limestone.
	1990-2154 "	Rock salt and shale.
	2154-2169 "	"Shale" (Anhydrite).
	2169-2250 "	Limestone.
	2250-2300 "	Rock salt.
800 feet Salina	2300-2340 "	"Shale," bluish (Anhydrite).
	2340-2360 "	"Sand."
	2360-2378 "	Shale.
	2378-2400 "	Limestone.
	2400-2420 "	Rock salt.
	2420-2430 "	"Shale."
	2430-2470 "	Limestone.
	2470-2475 "	Rock salt.
	2475-2483 "	"Shale."
	2483-2650 "	Limestone (Dolomite).
Niagara (?)	2650-2658 "	"Oil-sand" (Dolomite), rank with sulphur.
	2658-2680 "	Limestone.
	2680-2686 "	Oil-sand, free from sulphur.
	2686-2750 "	Limestone.
Niagara		Limestone of same general character.
Clinton	2750-3050 "	Bottom in red limestone with gas.

NEW RIVER (two miles south of grindstone quarries). Altitude 600 feet.

New River Salt Company. Depth 1029 feet.

Rominger, III, 77, 201. "Salt brine was already found at a depth of 90 feet below the surface, but it continued to increase in strength as a greater depth was reached."

Epoch.	Total depth.	Thickness.	Formation.
	1-15 ft.	15 ft.	Grindstone.
	15-45 "	30 "	Blue shale.
	45-800 "		Alternate shale and sandrock.
Berea shale (?)	800-900? "		Rotten, bad smelling, soft rock.
Berea or Richmondville sandstone	900-1000?"	100 "	Porous, coarse grained white sandrock; brine 85°.
	-1029 "	Only a few ft.	Blue shale.

NILES, Berrien County. (Plate XLIV.)

NORRIS (North Detroit), Wayne County, 628 feet or 631 feet.

Report of well sunk for water at the Lutheran Deaf and Dumb Asylum, in September, 1884; in Detroit Tribune for April 24, 1885, 1886 or 1887.

"An unexpected answer was discovered to this question in September, 1884. Workmen were engaged in sinking a well for water at the Lutheran Deaf and Dumb Asylum at Norris, this county. When down about ninety feet the drill broke and farther operations were suspended. One night there was a terrible explosion—drill, sand, water and gas were thrown high in air. Some one lighted a match near the well and the gas ignited and nearly burned up a tree twenty feet away, and frightened everybody who saw it.

"Professors Henry and Duffield of Detroit were invited to inspect the strange phenomenon. Prof. Henry at once made a proposition to rent the well, agreeing to light the institution with the natural gas, and to give a certain per cent of the profit to the institution. He desired to manufacture lamp black and had patented a machine for that purpose. Prof. Duffield said it was gas, and thought the gas escaped through a rift in the rock, and if the well was drilled deeper plenty of gas could be obtained. But nothing was done; water was plenty, two loads of brick were dumped into the bottom of the well to prevent the gas from

roiling the water, and the directors of the institution were satisfied.

"The well has, however, proven a source of annoyance to them, for, despite the water, gas accumulates with great rapidity, the mischievous boys take great advantage of this, and often cause great damage by dropping a lighted match into the well. The well was visited by a Tribune reporter yesterday. It is situated about four hundred feet to the left and in the rear of the deaf and dumb institute. Approaching the well, an offensive odor is first perceived. The water which comes from the pump is found to be brackish and warm. On removing a few boards from the covering of the well, a strange sight is witnessed: But a few feet below the brink the water boils up as in a cauldron. Tiny bubbles form and float along over the surface. The odor most approaches that of swamp gas. The well, which is ten feet across and bricked up, is as black as an oven from the smoke caused by the burning gas; bricks cracked by the intense heat, and even the rafters are in places burned away. A satisfactory test was made that proves the gas still flows in considerable quantities under the most discouraging circumstances.

"The well was dug through white clay until the rock was struck, when the drilling ceased. Whether it was the gas-bearing rock that has been struck is not known, but probably not, as it generally lies from one thousand to two thousand feet below the surface. Swamp gas, it would seem, would not continue to flow steadily for a year and a half. If the rock could be shot it could easily be told what the result would be. Several natives of Norris said that gas escaped from the ground in several places near there and had done so for years.

"Norris is but ten miles from this city, and if gas should be discovered in any quantity there it could be piped here at a small expense. But why pipe it here? If there is natural gas at Norris, and there is every reason to believe there is, there is natural gas in this city. The formation of the rock is the same, and the surface indications give better prospects. There are now at least two wells on Woodward Avenue from which gas escapes—gas that can be burned, that has been burned."

Oscoda, Au Sable City, Iosco County. Altitude about 590 feet.

Smith, Kelly and Dwight.
Rominger, III, 184, 186, 201.
Depth of wells 1103 feet and 1070 feet respectively; same formation as at East Tawas and at Caseville (?).
C. E. Wright notes on a map that from 960 to 1040 feet the formation is sandstone.

Owosso, Shiawassee County. (At the Detroit and Milwaukee Railroad Station.)

Depth 307 feet.
Rominger, III, 137. (In the record there must be some mistake, as the sum is greater than 307 feet.)

Owosso, Sec. 5. (Plate XLV.)
Mr. Courier. Depth 1000 feet.
Rominger, III, 97.
This is probably the same as the well engraved.

Paw Paw, Van Buren County. Altitude (?).

Hon. John E. Ferguson reports the well unsuccessful.
Hon. C. D. Lawton records the finding of wood.

Petrolia, Ontario. (Plate XLVI.)

Pontiac, Oakland County, (Plate XLVII.)

Port Austin, Huron County. Altitude 597 feet.

C. E. Wright notes on a map that it is 940 feet to sandstone which is 65 feet thick. Blue shales overlie it.
(1) Ayres & Co. Depth 1198 feet.
Rominger, III, 77, 183, 201.
T. Sterry Hunt, Geology of Canada, 1866–1869, p. 220. "Surface rock is a sandstone of the Chemung." "At a depth of 1198 feet from the surface ____ a brine ____ 88°."

Na Cl	17.6161 per cent.
Ca Cl_2	3.1274
Mg Cl_2	1.5675
Ca SO_4	0.0129

(2) Mr. Skene. Depth 1225 feet.

One mile west of the village, 200 yards from the shore of the Bay.

Total depth.	Thickness.	Formation.
Few feet	Few feet.	Drift.
		Conglomerate band of grindstone series. Greenish blue micaceous sandrock.
125 feet.	Few feet.	Conglomerate. Current of fresh water.
-163 "	.....	Arenaceous shales.
At 204 "	.....	Gray sandstone.
204-315 "	.....	Signs of brine.
317 "	.....	Shales with arenaceous seams.
-336 "	20 feet.	Conglomerate sandstone.
336-1100 "	764 "	Bluish shale; but few sandstone strata; strong flow of fresh water.
1100-1120 "	.....	(?)
1120-1160 "	40 feet.	Bright red and chocolate shales.
-1225 "	.....	Sandstone, with brine.
		Shales.

Or, according to Wright,

1–275 feet, sandy shales.
275–1100 " blue and red shales.
1100–1200 " sandstone (porous).

Port Hope, Huron County. Altitude about 600 feet.

Depth 785 feet. (787 and 865 feet.)

C. E. Wright notes that it is 800 feet to the sandstone, which has a thickness of 65 feet. Rominger, III, 76, 201.

Thickness.	Formation.
1-16 feet...	Drift.
16-22 " ...	Greenish micaceous sandstone.
22-532 " ...	Blue, sandy shales.
532-533 " ...	Hard rock.
533-687 " ...	Dark blue shales.
687-716 " ...	Arenaceous shales.
716-787 " ...	Sandstone; coarse; whitish; with strong brine.

PORTLAND, Ionia County.

In Engineering and Mining Journal, August 10, 1889, a strike of oil was reported here. Enquiry shows that nothing came of it, and that whatever happened was of no scientific importance.

PORT HURON, St. Clair County. Altitude 633 feet at the U. S. signal station, 589 feet at Port Huron, *i. e.*, at Fort Gratiot on the Grand Trunk railway track. (Plates XLVIII–LVII.)

There are a number of wells about here of which we have more or less of a record as given below. Mr. Bailey reports having sunk over thirty. These wells generally yield a little oil and gas.

Description of wells.	Depth of wells.
1. Bailey, C. A.; No. 1, 500 paces N., 1000 paces W., Sec. 9, T. 6, R. 17, one-half mile north and one and a half east of the Grand Trunk Junction well	668 feet.
2. Bailey, C. A.; No. 2	640 "
3. Bailey, C. A.; No. 3	530 "
4. Chadwick; east and west center line of S. 15, T. 6, R. 17. Church & Co. See Marysville.	498 "
5. Gordon, T. J. (Gordon and Hall)	572 "
6. Howard, Henry	498 "
7 Grand Trunk Junction well	772 "
8. McMorran; No. 1	615 "
9. McMorran; No. 2	550 "
10. Lakeport gas well, John Cole's farm. (Refer to Mr. Geo. P. Voorhees.)	
11. White, Edgar; gas well, corner of Military and Griswold streets, one-half mile north of the Chadwick well, supplying two houses	498 "
12. Wells, Fred L.; "Port Huron Gas well" and Port Huron salt well	1700 "

PORT LAMBTON, Ontario, Canada. (Plate LVIII.)

PORTSMOUTH, Bay City, Bay County. Altitude 592 feet (?).

Winchell, 1860, p. 154.

The bottom of the well is in the "Napoleon Group" (Marshall), which at this place is, according to Winchell, 88 feet thick.

C. E. Wright.

Rominger, III, 182, 200.

	Depth of wells.	
	Acc. to Rominger.	Acc. to Wright.
John W. McGraw & Co.	1000 feet.	925 feet.
N. Watrous & Son	1000 "	
A. M. Miller	1050 "	

At 664 feet, 54° brine, the upper salt-bearing rock containing more gypsum and less of chlorides.

RICHMONDVILLE, Sanilac county. Altitude 590 feet (?).

C. E. Wright.

The Berea (?) sandstone outcrops here and is found at steadily increasing dips, going north, at White Rock, Sand Beach, Port Hope and Port Austin.

RIFLE RIVER, Arenac County. (The Station, Alger, has the altitude 781 feet.)

Depths, 122 feet, 200 feet, etc.

Rominger, III, 141 144.

ROMEO, Macomb County. (Plate LIX.)

ROYAL OAK, Oakland County. Altitude 665 feet. (Plate LX.)

(1) "Developing Company." Depth 1400 feet.

Epoch.	Reference.	Thickness.	Formation.
Quaternary		1-40 ft.	Blue clay.
		40-50 "	Gravel.
		50-100 "	Blue clay.
		100-105 "	Black gravel (?).
Ohio or St. Clair	F. L. Wells, Port Huron, 185	105-230 "	Black shale.
Hamilton or Traverse	F. L. Wells, Port Huron, 290	250-392 "	Soft calcareous shale
	"Middle Lime"	392-520 "	Hard limestone.
	F. L. Wells, Port Huron, 315	520-545 "	Calcareous shale.
Helderberg	"Lower Lime"	545-1400 "	Hard limestone.

(2) See Plate.

SAGINAW, Saginaw County. Altitude 590 feet.

Rominger, III, 182, 200. A large number of firms with wells ranging in depth from 741 feet down to 830 feet.

C. E. Wright. See also East Saginaw, Carrollton, Zilwaukee.

	Total depth, acc. Rominger.	Total depth through sandstone, acc. to Wright.
Sturtevant and Green	830 feet.	860
Swift and Lockwood	860 "	860 } Rominger, III, 182, Lower salt rock.
Barnard and Binder	830 "	
Conrad Kull	802 "	
Geo. F. Williams & Bro.	800 "	835
C. T. Brenner	770 "	
Pierson, Wright & Co.	741 "	

SAINT CLAIR, St. Clair County. (Plates LXI and LXII.)

SAINT IGNACE, Mackinac County. (Plate LXIII).

St. Johns, Clinton County. Altitude (?)

A. W. Simmons (of Albion College, teacher at Calumet,) reports that there was a well sunk here for artesian water to the depth of 1200 feet, without finding good drinking water.

St. Louis, Gratiot County. Altitude (?).

Mr. A. W. Simmons (see St. Johns) says that there used to be a famous sanitarium with a deep well there. This well is also mentioned in Peale's work on mineral waters. We have not been able to secure the record.

Salzburg, West Bay City, Bay County. Altitude 590 feet (?).

Rominger, III, 200.
W. H. Malone, 1023 feet.
Ladrach Bros., 1000 "
L. L. Hotchkiss, 1013 "

Sand Beach, Huron County. Altitude 600 feet.

(1) J. Jenks & Co. Depth 715 feet, Wright; 702 feet, Rominger; 800 to 900 feet, according to G. J. Jenks, private communication, 1893.

It is referred to by Garrigues in Rominger, III, 184, and an analysis by S. P. Duffield is given. It is about 430 feet north by east from well No. 2. It is said that 98.7% of the solids are Na Cl, but this is slightly purer than Duffield's analysis indicates. According to Wright's notes it is 650 feet to the sandstone, which is 65 feet thick.

(2) Sand Beach Mineral Bath Company. We owe our information about these wells largely to the kindness of Geo. J. Jenks. Located on a salt reserve 400 feet east of a point where State street crosses the Flint & Pere Marquette railroad. Begun and finished in August, 1890. We cannot from the record infer the position of the Dundee, *i. e.*, Corniferous, with certainty.

Formation. Local names.	Equivalent depths in adjacent wells.	Total depths.	Record.
Coldwater or Waverly. Berea shale ?	Bay City 1548-1798	1-500 ft.	Blue slate or shale.
	Bay City 1798-1883	500-603 "	Black slate.
	Bay City 2093-2118		
	White Rock 450	603-623 "	Slate and sand
	Bay City 2118-2133		
	Forestville 505	623 "	Small flow of bitter water
Cichmondville or Berea	White Rock 550		Salt rock.
	Port Hope 787		
	Grindstone City 1080	633 "	Large flow; passes through salt rock; 8 in. casing from the top of the well to a depth of 674ft.
	Pt. Austin 1200		
	Caseville 1770		
	Bay City 2300		
St. Clair	Bay City 2306-2371	664-850 "	Light colored slate.
	Bay City 2371-2585	850-1120 "	Dark brown or black slate.
Traverse	Port Huron 185	1120-1725"	Light slate or soapstone, except 15 ft. of extremely hard rock at 1400.
	Muskegon 1700		
	Middle limestone of the St. Clair river (417-458 ?) or of the Corniferous (540), Cf. Bay City, 2822	1400 "	
Dundee ?	Bay City 2822	At 17?? "	Limestone.
	Port Huron 540?		
	Port Huron 660?	At 1844 "	Seemed to be lime and sand (dolomite ? L.) mixed and very fine at first, gradually growing coarser, which continued until drilling was stopped at 1920 ft.

Formation. Local names.	Equivalent depths in adjacent wells.	Total depths.	Record.
Monroe ?	Cf. Port Huron, 735	At 1860 ft.	Small flow of bitter water enough to drill with, smelling of oil just before striking the bittern.
	Cf. Port Huron, 892 and 945	At 1875 "	Heavy flow of salt water which rose to within 60 ft. of the surface in a few moments.
		1920 "	

An analysis of this lower bittern, by Samuel P. Duffield, is as follows (columns 1 and 2); one by Prof. R. C. Kedzie, in August, 1890 (column 3):

Specific gravity at 60° Fahrenheit, 1.180.

	(1.) Grammes per litre. 1. 180kg.	(2.) Grains per imperial gallon.	(3.) Grains per imperial gallon.
Calcic sulphate	.9936	69.552	63.00
Calcic chloride	62.6636	4,386.459	3,982.30
Magnesic chloride	5.3542	374.798	339.50
Magnesic bromide	24.8400	1,738.800	1,575.00
Potassic chloride	37.7788	2,644.521	2,395.40
Sodic chloride	179.2391	12,546.739	11,384.80
Silica	.7303	51.131	
Total solids	311.5996	21,812.000	19,740.00

Hydric Sulphide Gas .2271. 10.745 cubic inches: 10.5 cubic inches

TOTAL SOLIDS PER LITRE.

By direct estimation 311.6000 Grammes.
By actual analysis 311.5996 "

Loss .0004 Grammes.

The same bittern has also been analyzed by W. G. Merritt, with results almost identical with those of Duffield.

SANDSTONE, Jackson County. Altitude 956 feet.

Rominger, III, 128.

Winchell, 1860, p. 151.

SANDUSKY, Erie County, Ohio. Altitude 578 feet to 639 feet.

Bay City Natural Gas, Oil and Fuel Supply, and Electric Light Company.

Jacob Kuebler.

Geol. Survey of Ohio, VI, 194.

Thickness.	Epoch.
1-10 feet.	Drift.
10-110 "	Upper Helderberg.
110-1080 "	Lower Helderberg and Niagara. Gypsum at intervals from 110-980; at 960 water with sulphur: gypsum bed 9 feet thick at 275 feet.
1080-1185 "	Niagara and Clinton.
1185-1360 "	Medina.
1360-1860 "	Hudson River.
1860-2170 "	Utica. [Utica lies directly on Trenton. Forty feet not accounted for.]
2210-2260 "	Trenton.
	At bottom, gas, oil and salt water.

SEBEWAING, Huron County. Altitude 593 feet.

Lawton, Rept. Com. Min. Statistics, Mich., 1891, p. 66.

Coal 60-80 feet below the surface.

W. L. Webber (private communication May 24, 1891).

"There are two coal shafts * * * taking out over 100 tons a day. * * * In the vicinity there have probably been thirty or forty test holes put down. There are also many artesian wells, flowing and spouting water. * * * The Bay Port quarries (lime) also have developed an opportunity for geological studies." Of the rock we have reported the following:

Test at Watertown Arsenal, Mass. Bay Port stone resisted a crushing test of 26,000 lbs. per square inch, and Capt. Butler, who made the test, says: "It looks as though you ought to be able to build a tower three miles high, without fear of the bottom courses."

Weight, per cubic foot, 170 lbs.

Specific gravity, 2.72.

One cubic yard Bay Port stone crushed and carefully spread three inches thick will cover 108 square feet.

Analysis by Professor Langley, of Pittsburgh, Penn.

	Per cent.
Silica	3.330
Oxide lime and alumina	1.334
Carbonate of magnesia	.944
Carbonate of lime	91.538
Phosphorus and sulphur	traces.
Organic matter and loss	2.854
(Quicklime, 51.29.)	

Prof. Langley says: "This is very pure limestone, and is unusually free from anything except carbonate of lime. It contains nothing injurious to iron, and in my opinion it will give entire satisfaction in the blast furnace."

The following analysis is of the coal of the Saginaw Bay Coal Company, on S., T. & H. R. R., W. L. Webber, President:

	By Dr. W. H. Coffron, of Washington, D. C., 1889.	By E. Speidel, of Chicago, Ill., 1892.
Moisture	4.46	4.82
Volatile carbon	47.92	44.58
Fixed carbon	40.45	41.52
Sulphur	3.05	3.38
Ash	4.04	5.70
	99.93	100.00

Bay Port Springs is a well from a sandstone about 15 feet above the level of the bay.

Analysis given on p. 32.

South Bend, Indiana. (Plate LXIV.)

Spring Lake, Ottawa County. Altitude 596 feet. (See Fruitport.)

Stronach, Manistee County. (Plate LXV.)

Sylvania, Lucas County, Ohio. Altitude (?).

Geol. Survey of Ohio, VI, 225.

On the extension of the Findlay break (?); an anomalous section. Rominger, III, 28. A sandrock intercalated between Upper and Lower Helderberg limestones. P. 29. The upper part of the Lower Helderberg brecciated and recemented.

Swan Creek Village, Fair Haven, St. Clair County. Altitude about 600 feet (?).

Steven Rose's farm, nine miles west of Algonac. Depth 60 feet. C. E. Wright.

A large amount of gas in a shallow well.

Toledo, Lucas County, Ohio. Altitude 580 feet to 651 feet.

Geol. Survey of Ohio, VI, 208.

Four to five wells sunk here, of which the following is a sample:

Epoch.	Thickness.	Formation.
	1-80 feet.	Clay.
	80-120 "	Sand and gravel.
	120-585 "	Upper limestone.
	585-590 "	Blue slate.
	590-740 "	"Stray lime," gas at 700 feet.
Hudson R. and Utica	740-1415 "	Slate and shale.
	1415-1425 "	Trenton.

Traverse City, Grand Traverse County. Altitude (?).

T. T. Bates (Editor Traverse City Herald). Well committee. To be sunk April, 1892 (?). No farther reports.

Tuscola, Tuscola County. Altitude (Cf. Vassar, 643 feet).

See Winchell, 1860, p. 154.

West Sister Island, Ohio.

Geol. Survey of Ohio, I, 589.
Section of 90 feet. Gypsiferous limestone with strontianite.

White Rock, Huron County. Altitude about 600 feet.

Thomson Brothers. Depths 555 feet, 700 feet, 1311 feet.
Rominger, III, 76–77, 184, 201 (at p. 106 the reference should be to White Stone Point).
C. E. Wright.

Thickness.	Formation.
(1) According to Wright:	
1-495 feet	Surface and blue shales.
495-555 "	Brown sandrock; brine 80° at 45° F., same as at Port Austin, Port Hope and Sand Beach.
555-1311 "	Alternating strata, blue shale and limestone, shale predominating 20 to 1. From 600 to 610 feet down, a three-foot stratum of gaseous black shale was found.
	This latter is not far from the position of the Berea shale but comes below the sandstone which we take to be the Berea. Can it correspond to the Sulphur Island shales, and is the St. Clair formation black only in streaks? In that case very likely the Traverse really replaces it. L.
(2) Accord'g to Rominger:	
1-450 feet	Blue shales with sandy layers containing much pyrite.
450-550 "	Porous gray sandstone, with a strong, pure salt brine.

Williamston, Ingham County. Altitude 891 feet.

Rominger, III, 135–136 (six sections in the Coal Measures).

Winona, West Bay City, Bay County. Altitude 600 feet (?).

H. W. Sage & Co. Depth 1020 feet.
Rominger, III, 200.

WOODVILLE, Jackson County. (Three miles from Jackson.)

Rominger, III, 126.
Winchell, 1860, p. 154.

WYANDOTTE, Wayne County. (Plate LXVI.)

YORK, Washtenaw County. Altitude 703 feet.

Winchell. Geology of Washtenaw County, in history of Washtenaw County, p. 27.
See also Milan.
W. ½, N. E. ¼. Sec. 34, T. 4 S., R. 6 E.

Total depth.	Formation.
10 feet	Soil, subsoil and sand.
110 "	Clay, boulders and some sand; clay firm, sometimes dark.
112+ "	Shale very dark continuing.

YPSILANTI, Washtenaw County. Altitude 714 feet.

(1) T. C. Owen, "Atlantis Mineral Well." Depth 808 feet.
C. E. Wright.
(2) Moorman Well, A. A. Elliott, Superintendent.
(3) Ypsilanti Mineral Spring and Water Company.

ZILWAUKEE, Saginaw County. Altitude 590 feet (?).

Depth 800–860 feet.
C. E. Wright; Rominger, III, 185, 200.

	Total depth.	Total depth through sandrock. Wright.
A. T. Bliss & Bro.	835 feet.	810 feet.
John F. Driggs & Co.	840 "	
Rust, Eaton & Co.	800 "	838 "
New York and Michigan Solar Salt Co. / Oneida Salt Co.	860 "	

GENERAL INDEX.

Acervularia 61
Adrian 44
Adschi-Darja xv
Agassiz, referred to xi
Agatiferous zone of Corniferous 26
Alabaster Point, Plaster at 31
Albion 44
  Mineral water at 32
Alcona 45
Alger 78
Algonac 45, 71, 85
Allegan 13, 26, 45
Alluvial deposits 14
Alma 45
Alpena 25, 28, 34, 42, 46
  Depth of salt at 28, 45
  Mineral water at 32
  Rock salt at 34
Alsace xxii
Altitudes of well-heads, errors in 3
  See also names of towns.
  of railway stations 4
American Geological R'w'y Guide, 61
Analysis of coal from Sebewaing 84
  limestone from Sebewaing 84
  solid residue (Ann Arbor) 49
  water from Alma 46
    from Bayport 32
    from Frankfort 59
    from Fruitport 60
    from Manistee 34
    from Midland 35
    from Mt. Clemens 70
    from Port Austin 75
    from Sand Beach 80, 82
Andrew, A., referred to xxii
Anhydrite xi
  cap over salt beds xvi
Anhydrite, Description and detection of 37, 38, 39
  mistaken for gypsum and marl 5
  Occurrences of 72
  Origin of ..... xvii, 31
  with salt 9, 27
Animal bodies, Fat of, nitrogen-free xxii
  Flesh of, nitrogen-bearing xxii
Ann Arbor 21, 47, 48, 49
Annual rings at Stassfurt ..... xvi, 9
Appalachian Mountains xviii
Arenac County 78
Ash Township, Mineral water of 32
Au Sable City 75
Ayers, Analysis by 35
Banks (West Bay City) 49, 50
Basin, Lower Peninsula of Michigan a geological ..... xvii, 8, 16, 17, 35, 43
  Center of 43
Basins (topographical) Formation of xi
Battle Creek 50
Bay City 16, 19, 20, 34, 42, 50, 51, 52, 56, 58, 69, 78, 81
  Berea sandstone under 20, 51
Bay County 49, 50, 58, 65, 78, 80, 86
Bay Port, Mineral water at 32, 83
Bay Port Springs 84
Bedford shale 21, 47
Benton Harbor 51
Benzie County 59
Berea (Richmondville) sandstone xviii, 10, 20, 21, 22, 33, 42, 46, 71, 73, 78, 81, 86
  shale 10, 22, 73, 81, 86

Berea, Compared with Medina 30
Berrien County 51, 73
Bischoff, G., referred to x
"Bitter-lake" xvi
Bitterns. See BRINES.
Bituminous shale, Detection of 38
Black shale 10, 20, 21, 24, 26, 30, 42, 47
a source of gas 14, 15, 21, 22, 36
mistaken for coal 5
Blackmar 51, 58
Berea under 20
Borings, Deep. See WELLS.
Brachiopods in Dundee Limestone 26
Branch County 52, 54
Coldwater shales in 19
Station 52
Breccia 26, 27
Brine 16, 17, 19, 21, 26, 28, 31, 32, 33, 34, 45, 47, 48, 49, 59, 69, 72, 73, 75, 78, 86
in Dundee formation 26
Laws of variation in quality of 33
Need of casing out 34, 36
See also SALT and MINERAL WATER.
Bromides xii, xxii, 16, 21, 32, 69
in Bay City Brines 32
most abundant in brines from center of basin 34
See also CHLORIDES.
Brown's Station 21
Brownstown Township, Mineral water of 32
Brumell cited 22, 36, 54, 65
Building-stone 1, 31, 83
Butterworth's Spring 33
Calhoun County 44, 50, 67
Calciferous 37
Cambrian xvii
Canada. See ONTARIO, BRUMELL, PETROLIA.
Canfield. See MANISTEE.
Carbonates of Lime. See LIMESTONE.
of iron. See SIDERITE.
of lime and magnesia. See DOLOMITE.
Carbon dioxide, Water charged with 32
Carboniferous, Base of 42
See JACKSON COAL GROUP,
Carboniferous. See MARSHALL, SUBCARBONIFEROUS and COLDWATER.
Carpathians xx
Carrollton 52
Caseville 21, 42, 52, 53, 75, 81
Caspian Sea xv, xx
Cass County 55
Caucasus Mountains xx
Cement 1
Charity Islands, Unconformities on 17
Charlotte 18, 44, 53
Strength of brine at 26
Cheboygan 53
Probable depth of salt below 28
Chemical industries 26, 35
Chemung xix, 75
Chert, Description and detection of 37–38
in Upper Helderberg 25
Chester 53
Chlorides xi, 16, 21, 32, 33, 34, 78
Economical uses of 35
See also SALT.
Classification, geological, Principles of 7, 8, 9
Stratigraphical, adopted 11
Universal, how obtained 8
Clay, Description and detection of 37–38
Fire-clay 15
Hardpan xxiii, 14
Quaternary 13
Cleveland, Ohio 47, 71
shale 47
Clifford 54
favorable region to bore for gas and oil 36
Climatic changes, Effect of 9, 29
Clinton, Ontario 61
County 80
formation 29, 72, 83
Coal 1, 5, 14, 15, 58
beds near surface 16, 31
Beds of, not connected with oil beds xx, xxiii
Beds of, transgress other beds 11, 14, 15, 16
Brown xxii
Description and detection of 5, 37, 38

Coal, Measures xvii, 1, 11, 14, 16, 31, 33, 41
See also JACKSON COAL GROUP.
Coldwater 52, 54
River 19
shales xviii, 19, 20, 47, 81
Change in 20
Column, Geological. See GEOLOGICAL, etc.
Conglomerate 9, 27
Limestone 26
Constantine 54
Corniferous xx, 25, 26, 27, 37, 46, 49 81
See DUNDEE.
Correlations. See DIVISION LINES.
Corunna 15, 54, 64
Ontario 54
Courtwright 54
Cretaceous xi, xx
Cross-sections through basin of lower Michigan 42
Crushing test of Bay Port limestone 83
Crystalline rocks, supposed principal source of salts x
Currents, Effects of 10, 16
Cuyahoga County, Ohio 71
shales, equivalent to Coldwater 19, 47
Dearborn, Mineral water at 32
Deep Borings. See WELLS.
Delphi 54
Delta deposits 14
Deposits from fresh water and from salt water, Contrasts in xxiii, 9
variable at the same epoch 8
Desiccation. Periods of, marked by gypsum xiii, 28, 29
Detroit 54
Gas near 23, 65, 74
Geological section through 42
Devonian xi, xx
Dienze xvii
Dip of strata, how computed from borings 3
Diphyphyllum 61
Discina 54
Division lines between formations, mark geographic or climatic change 9
Difficulties of drawing 10
Division, Crossing of 11
on map 41
Dolomite, Description and detection of 37, 38
mistaken or not recognized 5
Occurrence of, in Grand Rapids Group 17
Monroe Beds 26, 27, 28, 42
Niagara formation 29
with salt xi, 9 10
in Traverse Group 24
Trenton formation 30
Quality of lime made from 42
Dowagiac 55
Drift. See QUATERNARY.
Dual nomenclature. See CLASSIFICATION.
Duffield, S. P., Analysis by 70, 80, 82
Dundee 32
limestone xx, 26, 27, 35, 42, 46, 81
Limits of, ill defined 25
Mineral water of 32
East Saginaw 55
East Tawas 33, 52, 57, 75
Bromine manufacture at 34, 35
Eaton County 53, 57, 61
Eaton Rapids 33, 57
Economic products 31
Elkhart, Indiana 57
Engineering and Mining Journal cited 54, 65, 67, 77
Epsom salts, Recognition of, by taste 39
Erie County, Ohio 83
shale 47
Erosion. See UNCONFORMITY.
Essexville 58
Exeter Township, Mineral water of 32
Explanation of plates and maps 100
Fair Haven 85
Fauna of ocean and of fresh water xi
Favosites 61
Fire-clay. See CLAY.
Flagstone 18
Flexures in strata 35, 36, 43, 44
Flint 52, 58
-rock 5
Florence 58
Forestville 58, 81

Formations, Geological. See individual names of formations, also well-records of different towns.
Geological, of Mich. Some belong with Ontario and New York 2
Outcrops of, scarce in Lower Peninsula 1
Thickness of 1, 2, 11
in Ohio and Indiana 2
Fort Gratiot 77
Frankfort 13, 44, 59
Fredonia 69
Freestone 5, 37
See SANDSTONE.
Fruitport 33, 60
Galicia xx
Gannett, H., cited for altitudes 4, 40, 47
Garrigues, S. S., cited 20, 33, 34, 35, 80
Gas, Occurrence of xx, xxiv, 1, 20, 22, 26, 30, 31, 35, 47, 48, 49, 62, 63, 73, 74, 77, 83, 85
List of regions favorable for production of 21, 36
Marsh- xxii
Metamorphosing action of, on rocks xii
Structure of formation favorable for retention of xix, 35, 36
under impervious hard-pan 14
Geikie, A., cited 15
Genesee County 58
shales 45
Geological column 1, 7, 11
See also the different formation names.
formations. See FORMATIONS.
sections. See SECTIONS.
Gibraltar, Mineral water at 32
Glacial deposits 14
period. (Quaternary) 13
Glass sands. See SANDS.
Glauber salts, Recognition of, by taste 39
Goderich, Ontario 10, 27, 28, 61
Goshen, Indiana 60
Grand Haven 60, 61
Grand Ledge 61
at margin of coal basin 15
Grand Rapids 17, 31, 33, 61
Group 16, 17, 18, 41
not in adjacent states 19
Grand Traverse Bay, Black shale at 22
County 85
Geological section through 42
Gratiot County 45, 63, 80
Gravel 1, 13
See also QUATERNARY.
plains 14
Grindstone City 62, 81
Grindstones 18
Guelph formation 29
Gulf Stream, an agent of deposition 10
Gypsum xi, xiii, xviii, 5
Cause of precipitation of xvii
confounded with other deposits 5
Description and detection of, 37, 38, 39
Excess and deficiency of 34
Irregularity of gypsiferous series 17, 36
See also GRAND RAPIDS GROUP.
Occurrences of 17, 26, 27, 28, 51, 70, 78, 83
with salt 5, 16, 29
Hamilton xix, xx, xxi, 10, 24, 25, 26, 49, 79
See TRAVERSE.
Hard-pan. See CLAY.
Hat Point, Flexure near 44
Helderberg 28, 29, 40, 47, 68, 79
See Upper and Lower HELDERBERG and MONROE.
Hematite, Description and detection of 37
Hillsdale 42, 62
County, Coldwater shales in 19
Howell 62
Hubbard, Bela 1
Hubbardston, Mineral water at 32
Hudson River shale 30, 83, 85
Hunt, T. S., cited 27, 46, 51, 61, 65, 75
Huron County 53, 62, 75, 76, 80, 83, 86
Flexures of rocks in 36, 44

Huron County, Grindstones of 18
Salt wells of 20
Huron Shales 21
See ST. CLAIR SHALES.
Group 45, 49
Huronian xvii
Ida 10, 42
Imlay City 63
Indiana xviii, 2, 11, 42, 54, 57, 60, 68, 84
See also SOUTH BEND.
Ingham County 66, 68, 86
Inter-Ocean quoted 51
Iodine xii, xxii
Ionia 63, 64, 77
Iosco County 57, 75
Ithaca 63
Iron carbonate. See SIDERITE.
Jackson City 44, 65, 87
on margin of coal basin 15
Marshall group under 18
Wells at, a source of data for geological column 7
County 65, 83, 87
Jackson Coal Group xvii, 14, 55, 64
Jones, J. R., Analysis by 49
Kalamazoo 11, 27, 65
Kames 14
Kawkawlin 65, 69
Kedzie, R. C., Analyses by 32, 59, 82
Kent County 61
Kingstones Mills 65
Kingsville 65
Lamellibranchs 54
Lambton County 65
Langley, Prof., Analysis by 84
Lansing 33, 66
Mineral water at 33
Lapeer County 54, 63
Laporte County, Indiana 68
LaSalle, Mineral water at 32
Laurentian xvii
Lawton, C. D., cited 15, 75, 83
Leaching of salt deposits 33
Lenawee County 44
Leslie, Mineral water at 32
Lime 1
Limestone, associated with salt xii 9
Interruption of deposits of xvi
called dolomite and soapstone 5
Description and detection of, 37, 38
Limestone, Formation of xiii, 8
in Coldwater Group 19
Monroe beds 28
Niagara formation 29
Traverse Group 24, 25
Trenton 30
Quarries at Bay Port 83
Sandy (arenaceous) 10, 15, 16, 17
Subcarboniferous 53
See also DUNDEE.
See also plates and records.
Limonite, Description and detection of 37, 38
Lingula 54
Liquid measures compared 46
Lithology, Use of, in classification 7, 8, 11
Little Traverse 24
See TRAVERSE.
Livingston County 62
Local names, why used 11
how used, Pl. LXXIII.
Location of wells. See WELLS.
Logan conglomerate (= Marshall) 19
London, Artesian boring at 66
Lower Helderberg 10, 27, 69, 72, 83, 85
See MONROE BEDS.
Lower Peninsula of Michigan a basin xvii, 8, 16, 17, 35
Center of basin of 43
Geological formations of 13
Economic products of 31
Lower Silurian 30
Lucas County, Ohio 85
Ludington 13, 34, 66
Mackinac, Straits of, Gypsum near 28
Mackinac County 79
Mackinaw City, Dundee formation at 26
Macomb County 70, 78
Macon Creek, Dundee outcrops at 26, 66
Magnesia salts xv
See also BRINES, and SULPHATES.
Magnetic oxides in samples derived from drills 29
Manistee 13, 14, 34, 66
Black shale at 22
Brine from, analyzed 34

Manistee County 66, 84
Flexure near 44
salt horizon 59
Map of Lower Peninsula, Explanation and use of 7, 41, 100
Marble 1
Marengo 67
Marine City 67
Gas near 23
Gypsiferous limestone under 26
Marl, Gypsum, called 5
in Monroe beds 27, 28
in Quaternary 13, 14
in Traverse Group 25
with salt 9
Marshall 50, 56, 67
Group, the source of bromine at Midland 34
sandstone 13, 17-19, 20, 33, 34, 41, 42, 44, 46, 48, 50, 56, 61, 78
See also NAPOLEON.
Marysville 68
Mason County 66
Medina 30, 83
Mediterranean, Water of, rich in magnesian salts xv
Mean of winter temperature of xv
Melbourne 68
Mendelejeff's theory of the origin of petroleum xxi
Objections to xxi
Meridian 68
Mica 38, 48
Michigan City, Indiana 68
Michigan Salt Group 17, 46, 48
Michigan Geological Survey, Materials furnished by, for keeping records of wells 36
Midland 15, 19, 33, 68
Analysis of bittern from 35
the seat of bromine industry 34
Milan 69, 87
Milwaukee, Wisconsin 69
Mineral Statistics, Report of Commissioner of, cited 15
See also LAWTON.
Mineral waters 24, 32, 33, 45
Mississippi Valley xviii
Missouri, Coal measures of, compared with those of Michigan 11, 15
Monroe 10, 27, 44, 61, 69, 70
Beds xviii, xix, xx, 26, 27, 82
Medina and Trenton under 30
Mineral water at 32
Niagara under 28, 29
County 11, 19, 26, 28, 32, 47, 66, 69
Wells at, a source of data for geological column 7
Moraines 14
Mother liquors xxii
Mount Clemens mineral water 32, 70, 71
Mud. See SILT.
Muskegon 27, 44, 71 81
Oil and gas at 20
probable southern limit of salt deposits 34
Napoleon. Character of Marshall sandstone at 18
group 50, 78
proposed and abandoned by Winchell 18
Neues Jahrbuch für Geologie cited 31
Newburg, Ohio 71
Newberry, theory of cycles of sedimentation sustained 29
New River 72
New York xviii, 2, 28, 30
Extension of salt-depositing sea from Michigan to 27
Niagara formation 28, 29, 59, 66, 72, 83
Niles 4, 26, 42, 44, 72
Nomenclature, Principles of 11, 12
Norris (North Detroit), Gas near 73
Oakland County 75, 79
Ocean, currents 10
originally a saturated brine, x
Ochsenius x, xiii, xiv, xv, xvi, xvii, xxii
Ohio xviii, xxiii, 35, 71, 83, 85, 86
Formations in, equivalent to Michigan formations 10, 19, 21, 28, 29, 30, 31, 35, 43
Geological survey of, cited 4, 12, 29, 71, 83, 85, 86
on well measurements 4
Names used by 12, 41
Gypsum in xviii
State of emergence of, in Helderberg times xxiii, 27
See also SYLVANIA, TOLEDO, NEWBURG.

Ohio Shale 21, 47, 72
See St. Clair Shale, and Utica Shale.
Oil. See Petroleum.
in the Coldwater shales 20
in the Dundee formation 26
in Ontario 36
in the Trenton formation 31, 35
in the Utica shale 30
rock 5
sand 5, 21
Structure of formation favorable for retention of 35, 36
Ontario 2, 22, 36, 54, 61, 65, 75, 77
Formations of, equivalent to Michigan formations 19
Oriskany 41
Orton, E., cited 29, 72
See also Ohio, Geological Survey of.
Osankee County 69
Oscoda 21, 33, 75
Berea furnishes brine at 20
Comparative composition of brine at 21, 33
Otsego, Mineral water at 32
Ottawa County 60, 61, 84
Owosso 32, 64, 75
Oxidation, Effects of 18
Paleontology, Use of, in classification 7, 8, 11
Paleogeography 8
Paleozoic xi
Parma sandstone 15, 16, 17, 18, 33, 41, 55, 64
Paw Paw 13, 75
Peale, A. C., cited for analyses 32, 60, 66, 80
Peat 8, 14
Pennsylvania xxi
Pennsylvania, oil sands, Comparisons with 21, 35
Permian xi
Petrolia 75
oil field, Upper Helderberg, source of the 26, 35
Petroleum xi, xix, 1, 5, 45, 47, 48, 77, 83
associates of xxii
associated with salt water xxiv
deposits along old shore lines xxiii
Petroleum found in connection with remains of animal matter xx
Occurrence of, in Caspian District xx
California xx
Galicia xx
Michigan xx
Ontario xx
Pennsylvania xix, xx
porous rocks xix, xxi
South America xx
a product of animal fat xxii
of the action of water on carbon compounds of the metals xxi
action of carbon dioxide, etc., on iron and alkalies xxi
action of mother liquors xxii
of distillation xx, xxiii
Distillation, products of xxii
strata in California tilted xx
Tendency of, to seek surface of the earth xxiii
Plaster. See also Gypsum 1, 31
Plates of wells, Description and explanation of 40, 101
Point aux Barques 18
Flexure of strata near 36
Polyhalite xvii
Pontiac 75
Berea sandstone under 21
Port Austin 20, 33, 42, 75, 78, 81
Berea furnishes brine at 20
Comparative composition of brine at 21, 33
Port Hope 76, 78, 81
Port Huron 44, 68, 77, 79, 81
Gas near 23
Geological section through 44
Portland 77
Port Lambton, Ontario 77
Portsmouth 16, 78
Potash salts xi, xiii, xxi
See also Brines.
Potsdam sandstone xvii
Prescott, A. H., cited for analysis 34
Projections 43, 44
Pyrite, called sulphur 5

Pyrite, Decomposition of, in black shales ... 22
in Traverse group ... 24
in samples from borings ... 38
Quaternary ... 14, 48, 63, 79
Thickness of ... 13
Unconformable on other formations ... 13, 14
See also GRAVEL.
Quartz. See SILICA, sand and chert.
Raisinville, Mineral water at ... 32
Red Sea ... xiv
Richmondville ... 21, 78
sandstone 10, 20, 21, 33, 42, 47, 73, 81
See also BEREA.
Rifle River ... 78
River channels cutting out coal ... 15
Rock series. See GEOLOGICAL COLUMN.
Romeo ... 21, 78
Rominger, C., referred to or cited ... 1, 10, 12, 14, 15, 17, 18, 20, 21, 24, 26, 42, 44, 47, 49–55, 57, 58, 61, 62, 63, 65–73, 75, 78, 79, 80, 83, 86, 87
Rowland quoted ... 35
Royal Oak ... xix, 71, 79
Thickness of salt reported under ... 28
Saginaw ... 42, 79
Saginaw County ... 51, 52, 55, 58, 68, 79, 87
Saginaw Bay ... 68
Geological section through ... 42
River ... 7
Valley, source of brines of ... 19
Sahara, Desert of ... xiv
Saint Clair ... xx, 33, 47, 79
County ... 45, 67, 68, 77, 79, 85
Composition of brines at ... 33, 34
District ... 34
Lake ... 44
Mineral water at ... 32
River ... xix, 7, 22, 24, 28, 54, 68, 81
Shale ... 21, 22, 30, 42, 46, 47, 54, 79, 81
See BLACK SHALE.
Saint Ignace ... 79
Plaster at ... 31
Salt under ... 28
Saint Johns ... 80
Saint Joseph County, Indiana ... 54
Saint Louis ... 80
Mineral water at ... 32
Saline ... 27, 28, 33, 72
See MONROE.
Saline River ... 69
Salt ... 1, 28, 34
Age of deposits of ... xi
Amount of, required to saturate the ocean ... x
Annual rings in deposits of ... xvi, 9
Associates of ... xi
Aqueous theory of origin of ... xii
Brought by winds from the ocean ... x
Conditions of formation of ... 9, 16, 27, 29
Created by the atmosphere ... x
Crystalline rocks the principal source of ... x
Deposits covered by clay or sand ... xvi
Deposits of, irregular ... 36
Deposits of, Requisites for formation of ... xiv
distributed over the earth as a saturated brine ... x
horizons, in Michigan ... 16, 19, 20, 27, 28, 33, 81
Organic origin of ... x
Organic remains in deposits of ... 9
Rock-, not in Grand Rapids Group ... 17
Southern limits of ... 27, 28, 34
springs, at low points of outcrops ... 33
The ocean the great repository of ... xi
Thickness of beds of ... 51
Volcanic theory of origin of ... xii
water ... xxii, 45, 82, 83
fauna ... xi
See also BRINE.
"garden" ... xiii
Salzburg ... 80
Samples of borings, Material needed for tests of ... 36, 37
Sanatoria. See MINERAL WATERS.
Sand, Description and detection of ... 37, 38

Sand dunes 14
Glass-making 10, 27
in Quaternary 13
Sand Beach 33, 78, 80
Berea furnishes brine at 20
Composition of brine of 21, 28, 32, 33
Sandstone 83
cutting out coal 15
(= freestone and sandrock).
Dolomite, etc., called 5
occurrences 17, 18, 28, 42
See also numerous well-records. Also PARMA, MARSHALL, BEREA.
Sandusky, Ohio 83
Sanilac County 58, 78
Schleiden cited x
Sea Water, Amount of solid matter in x, xiv
Concentrated, Effect of, on animal life xiv, xv
Periods of evaporation of xiv
Products of evaporation of xiii
Salt deposits from, depend upon specific gravity of xvi
Sebewaing 15, 17, 83
Section, Geological, Description of 42
Use of 43
Shale 10, 15, 18, 24, 29
Argillaceous 30
Bituminous, Detection of 38
Bluish 24, 25, 30
See also TRAVERSE.
Calcareous, called soapstone, 5
Green 16, 17, 19, 30
See also Black shale and Ohio shale.
Red, represents sandstone 20, 21
Subcarboniferous 42
See Black shale and Ohio shale.
Also frequently in the well-records.
Shiawassee County 54, 75
Shore-lines, Deposits along xxiii, 8
Siderite, Detection and description of 37, 38
in coal measures 15
in Coldwater shales 19
Silica, Detection of, in boring samples 37, 38
Silt, Deposits of 8, 9
Silurian xi, xix, 10, 11
See also LOWER SILURIAN.
Soapstone (soap-rock), Popular use of name 5
Occurrences of 24, 25
South Bend, Indiana 11, 26, 29, 30, 84
Sperenberg, Thickness of salt deposit of xi
Spring Lake 33, 84
Stassfurt, Salt deposits of xi, xiv, xvii, 9, 28
State Geological Survey, furnishes free material for keeping records of wells 36
Stigmaria 54
Stony Point, Character of Marshall at 18
Straits of Gibraltar, currents at the xv
Strike of strata, how computed 3
Stronach 84
salt horizon 59
Strontianite 86
Subcarboniferous 34, 42
See also GRAND RAPIDS, MARSHALL and COLDWATER.
of Pennsylvania 35
Sulphates xi, xvii, 5, 16, 22, 28, 32
See also GYPSUM and ANHYDRITE.
Sulphide of hydrogen 32, 82
Sulphur, associated with salt xi
formed by action of sulphates on organic detritus xxii
in petroleum xxii
Island 22
springs 32
What called 5
Surface topography 1
rocks. See QUATERNARY.
Swan Creek 85
Gas near 23
Sylvania, Ohio 10, 42, 85
sandstone 72
Systems, Geological 12
Taymouth, Township 51
Tawas, Source of brines of 20, 21
Flexures near 36, 44
Temperature of mineral waters 6

Temperature of rocks ... 6
gradient of the earth's crust, 45, 59, 66
Tertiary ... xi, xix, xx
Terrace epoch ... 13, 14
Tests used by well-drillers ... 36
Thickness of drift. See QUATERNARY.
of rock series. See FORMATIONS.
See also individual formation names.
Thunder Bay ... 22
River ... 47
See ALPENA.
Tittabawassee River ... 68
Toledo, Ohio ... 42, 85
Topography, Surface ... 1
Traverse City ... 85
Group xx, 10, 24, 42, 47, 79, 81
Blue shale of ... 42
forms transition between St. Clair and underlying limestone 24
Thickness of ... 24
Trenton ... 1, 30, 83
the oil horizon of Ohio and Indiana ... xx, 35
Trias ... xi
Tungsten, an indication of mother liquors ... xxii
Tuscola ... 85
Unconformity ... 13, 14, 16, 17
Upper Helderberg ... 10, 25, 32, 61, 72, 83, 85
See DUNDEE.
Usiglio, referred to ... xiii, xvi
Utica shale ... 30, 83, 85
Van Buren County ... 75
Variation in composition of brines, in life and deposition, local, 1, 8, 9, 14, 16
in Ohio ... 29
of the Medina ... 30
Vassar ... 13
Washtenaw County ... 69, 87
Black shales under ... 47
Water, Drinking ... 44
Wauwatosa ... 69
Waverly ... 10, 20, 81
See COLDWATER.
Wayne County ... 32, 54, 73, 87
Well-heads, Altitude of ... 3
Wells, Alphabetical list of ... 44, 100
Errors in samples from ... 6
Location of ... 3, 101
Material for keeping samples and records of ... 36
Measurements of ... 4, 5
Records of, how they should be made ... 6
Errors in ... 4, 5, 6
how derived ... 40
when incomplete ... 2
when trustworthy ... 5
Samples from ... 36, 37
Towns where situated, underlined on Map ... 101
Werner, referred to ... 7
West Bay City. See BANKS and SALZBURG.
West Sister Island ... 86
Wheeler, C. G., Analysis by ... 60
White Rock ... 33, 86
Berea furnishes brine at 20, 78, 81
White Stone Point ... 86
Williamston ... 68, 86
Winchell, A., referred to ... 1, 12, 15, 17, 18, 21, 24, 25, 26, 42, 44, 45, 47, 48, 50, 53, 55, 61, 65, 66, 78, 83, 85, 86, 87
Winchell, N. H. ... 24, 25, 53
Winona ... 86
Winslow, A., cited ... 11, 15
Wisconsin ... xviii, 69
dry land at time of Salina ... 27
Geological Survey of ... 69
See MILWAUKEE.
Wood found in Quaternary ... 13
Woodville ... 87
sandstone ... 15, 64
Wright, C. E., referred to ... 3, 12, 15, 21, 40, 41, 42, 45, 50, 51, 52, 53, 55, 57, 58, 59, 61, 62, 68, 71, 75, 76, 78, 79, 80, 85
Wyandotte ... xix, 27, 28, 29, 30, 32, 87
Thickness of salt under ... 82
Niagara beneath ... 29
mineral water ... 32
probable southern limit of salt deposit ... 34
York ... 87
Ypsilanti ... 87
Mineral water at ... 32
Zilwaukee ... 87

INDEX

TO RECORDS OF BORINGS.

Adrian, T. 7 S.,R. 4 E. (Plate I.) 44
Albion, T. 2 and 3 S., R. 4 W. 44
Alcona, T. 27 N., R. 9 E. 45
Algonac, T. 2 N., R. 16 E. (Plates II and III.) 45
Allegan, T. 2 N., R. 13 W. (Plate IV.) 45
Alma, T. 11 N., R. 3 W. 45
Alpena, T. 31 N., R. 8 E. (Plate V.) 46
Ann Arbor, T. 2 S., R. 6 E. 47
Au Sable. See OSCODA.
Banks, T. 14 N., R. 5 E. 49
Battle Creek, T. 2 S., R. 8 W. 50
Bay City, T. 14 N., R. 5. E. (Plate VI.) 50
Bay Port Springs. See SEBEWAING.
Benton Harbor, T. 4 S., R. 18 W. (Plate VII.) 51
Blackmar, T. 10 N., R. 5 E. 51
Branch Station. (See COLDWATER.) 52
Carrollton, T. 12 N., R 5 E. 52
Caseville, T. 18 N., R. 10 E. 53
Charlotte, T. 2 N., R. 4 and 5 W. (Plate VIII.) 53
Cheboygan, T. 38 N., R. 2 W. 53
Chester, T. 3 N., R. 5 W. 53
Clifford, T. 10 N., R. 11 E. (Plate IX.) 54
Coldwater, T. 6 S., R. 6 W. (Pltae X.) 54
Constantine, T. 7 S., R. 12 W. (Plate XI.) 54
Corunna, T. 7 N., R. 3 E. (Plate XII.) 54
Corunna, Ontario.
Courtwright, Ontario, opposite T. 5 N., R. 17 E. (Plate XIII.) 54
Deep River. See RIFLE RIVER.
Delphi, Indiana. (Plate XIV.) 54
Detroit, T. 1 and 2 S., R. 11 and 12 E. (Plate XV.) 54
Dowagiac, T. 6 S., R. 15 and 16 W. (Plate XVI.) 55
East Saginaw, T. 12 N., R. 5 E. 55
East Tawas, T. 22 N., R. 8 E. 57
Eaton Rapids, T. 1 N., R. 3 W. 57
Elkhart, Indiana. (Plate XVII.) 57
Essexville, T. 14 N., R. 5 E. 58
Flint, T. 7 N., R. 7 E. 58
Florence, Saginaw County(?) 58
Forestville, T. 14 N., R. 16 E. 58
Frankfort, T. 26 N., R. 16 W. (Plate XVIII.) 59
Fruitport, T. 9 N., R. 16 W. 60
Goshen, Indiana. (Plate XIX.) 60
Goderich, E. shore of Lake Huron, Ontario 61
Grand Haven, T. 8 N., R. 16 W. 61
Grand Ledge, T. 4 N., R. 4 W. 61
Grand Rapids, T. 7 N., R. 12 W. (Plates XX and XXI.) 61
Grindstone City, T. 19 N., R. 13 E. 62
Hillsdale, T. 6 S., R. 3 W. 62
Howell, T. 2 N., R. 4 E. 62
Imlay City, T. 7 N., R. 12 E. (Plate XXII.) 63
Ionia, T. 7 N., R. 6 and 7 W. 63
Ithaca, T. 10 N., R. 2 W. 63

Jackson, T. 2 S., R. 1 W. (Plates XXIII–XXV.) 65
Kalamazoo, T. 2 S., R. 11 W. (Plate XXVI.) 65
Kawkawlin, T. 15 N., R. 4 E. 65
Kingsville, Ontario. 65
Kingstone's Mills, Lambton Co., Ontario 65
Lansing, T. 4 N., R. 2 W. 66
London, T. 5 S., R. 7 E. 66
Ludington, T. 18 N., R. 18 W. (Plates XXVII–XXIX.) 66
Manistee, T. 21 N., R. 17 W. (Plates XXX–XXXII.) 66
Marengo, T. 2 S., R. 5 W. 67
Marine City, T. 3 N., R. 16 E. (Plates XXXIII–XXXIX.) 67
Marshall, T. 2 S., R. 6 W. 67
Marysville, T. 5 N., R. 17 E. (Plate XL.) 68
Melbourne, T. 13 N., R. 5 E. 68
Meridian, T. 4 N., R. 1 W. 68
Michigan City, Laporte Co., Ind. 68
Midland, T. 14 N., R. 2 E. 68
Milan, T. 4 S., R. 6 E. 69
Milwaukee, Milwaukee Co., Wis. 69
Monroe, T. 7 S., R. 9 E. (Plate XLI.) 69
Mt. Clemens, T. 2 N., R. 13 E. (Plate XLII.) 70
Muskegon, T. 10 N., R. 16 W. (Plate XLIII.) 71
Newberg, Cuyahoga Co., Ohio 71
New River, T. 19 N., R. 14 E. 72
Niles, T. 7 S., R. 17 W. (Plate XLIV.) 73
Norris, T. 1 S., R. 12 E. 73
Oscoda, Au Sable City, T. 23 N., R. 9 E. 75
Owosso, T. 7 N., R. 2 E. (Plate XLV.) 75
Paw Paw, T. 3 S., R. 14 W. 75
Petrolia, Ontario. (Plate XLVI.) 75
Pontiac. T. 3 N., R. 10 E. (Plate XLVII.) 75
Port Austin, T. 19 N., R. 13 E. 75
Port Hope, T. 17 N., R. 15 E. 76
Portland, T. 6 N., R. 5 W. 77
Port Huron, T. 6 N., R. 17 E. (Plates XLVIII–LVII.) 77
Port Lambton, Ontario. (Plate LVIII.) 77
Portsmouth, T. 14 N., R. 5 E. 78
Richmondville, T. 13 N., R. 16 E. 78
Rifle River, T. 19 N., R. 4 & 5 E. 78
Romeo, T. 5 N., R. 12 E. (Plate LIX.) 78
Royal Oak, T. 1 N., R. 11 E. (Plate LX.) 79
Saginaw, T. 12 N., R. 4 E. 79
Saint Clair, T. 5 N., R. 17 E. (Plates LXI–LXII.) 79
Saint Ignace, T. 40 N., R. 5 W. (Plate LXIII.) 79
St. John's, T. 7 N., R. 2 W. 80
St. Louis, T. 12 N., R. 3 W. 80
Salzburg, T. 14 N., R. 5 E. 80
Sand Beach, T. 15 N., R. 15 E. 80
Sandstone, T. 2 S., R. 2 W. 83
Sandusky, Erie Co., Ohio 83
Sebewaing, T. 15 N., R. 9 E. 83
South Bend, Ind. (Plate LXIV.) 84
Spring Lake, T. 8 N., R. 16 W. 84
Stronach, T. 21 N., R. 16 W. (Plate LXV.) 84
Sylvania, Lucas Co., Ohio 85
Swan Creek Village, T. 3 N., R. 15 E. 85
Toledo, Lucas Co., Ohio 85
Traverse City, T. 27 N., R. 11 W. 85
Tuscola, T. 11 N., R. 7 E. 85
West Sister Island, Ohio 86
White Rock, T. 15 N., R. 16 E. 86
Williamston, T. 3 N., R. 1 E. 86
Winona, T. 14 N., R. 5 E. 86
Woodville, Jackson Co., 3 miles west of Jackson 86
Wyandotte, T. 3 S., R. 11 E. (Plate LXVI.) 87
York, T. 4 S., R. 6 E. 87
Ypsilanti, T. 3 S., R. 7 E. 87
Zilwankee, T. 13 N., R. 5 E. 87

EXPLANATION OF PLATES AND MAP.

On the map the cross-sections are indicated by red lines. Places from which there are well-records are underlined in red. The other red lines (broken, dotted, etc.,) indicate outcrops of division lines between the formations. For farther explanations see text, p. 40.

In the geological column and in all of the sections, similar symbols are used for the same kind of rock, viz.:

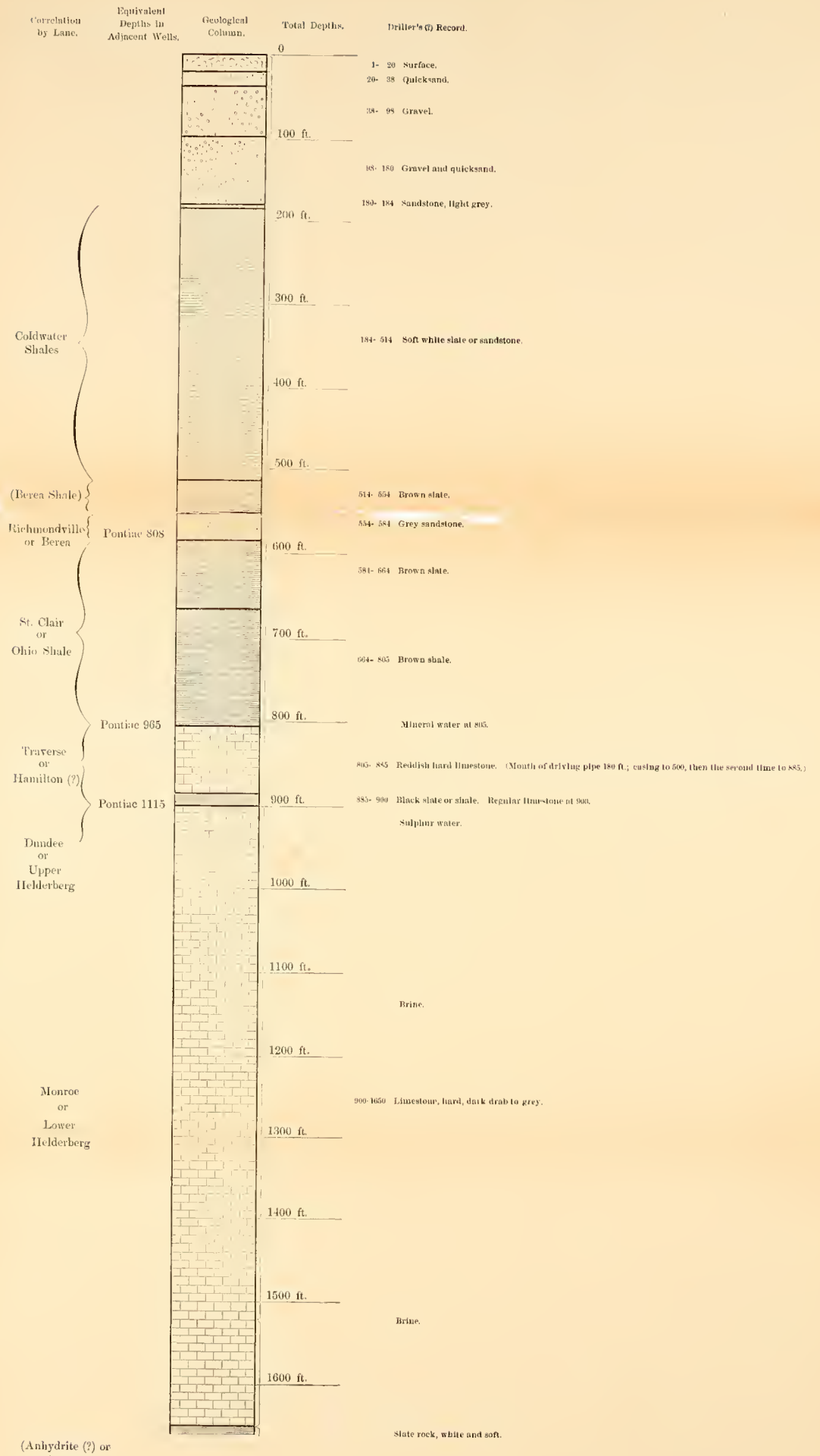
Vertical and horizontal lines	Dolomite.
The same, broken-jointed	Limestone.
Dots, for an arenaceous ingredient or	Sandstone.
Dashes for an argillaceous ingredient or	Shale.
Oblique lines in one direction	Gypsum.
" " " two directions	Salt.

In sections across the basin, the circular and direct projections of places are connected by arrows. See text, p. 43.

Other abbreviations are:

§ for point where one cross-section is cut by another.
B. for horizon of brine, bittern or mineral water.
R. for river.
R. R. for railroad.
L. H. for Lower Helderberg.
U. H. for Upper Helderberg.

Lenawee Co., Alt. 810 ft.
Adrian Gas Co. Depth, 1650 ft.
C. E. Wright; no samples.

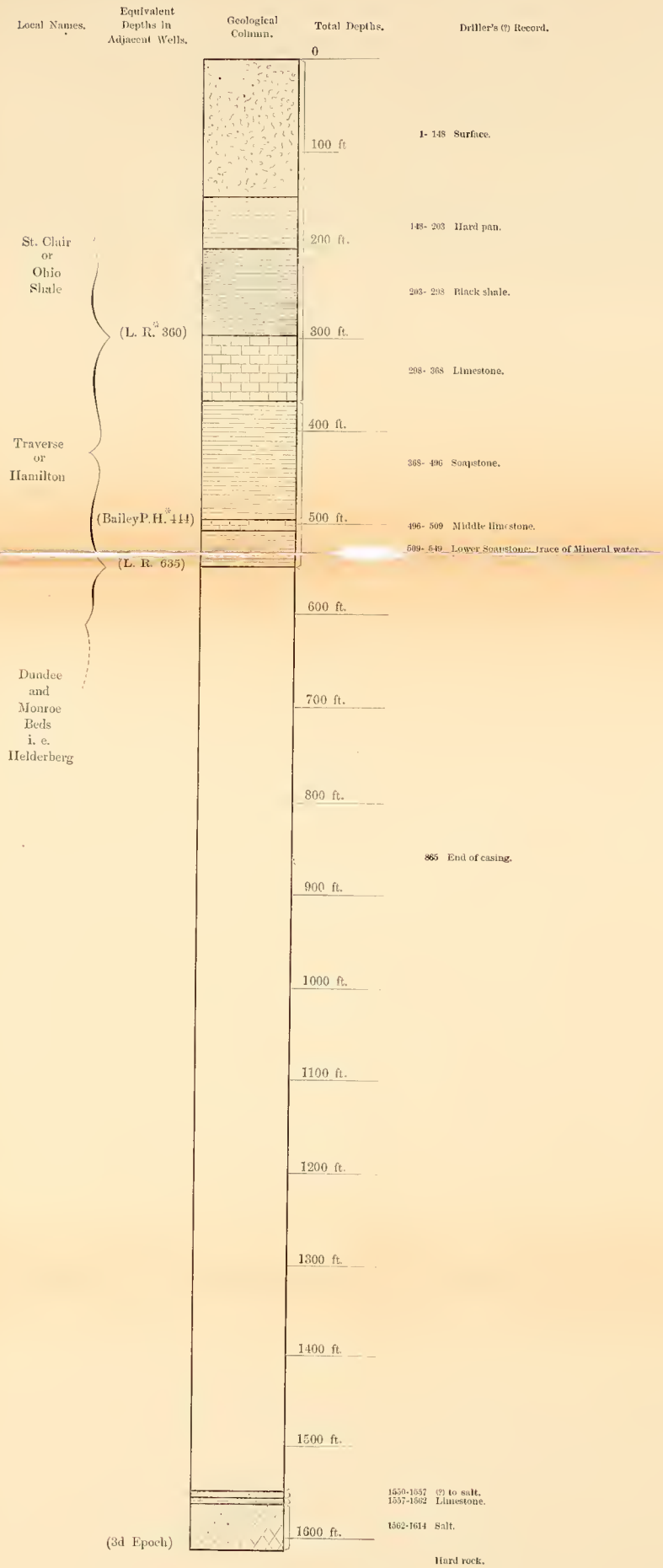


Albert Miller. Depth 1727 ft.
C. E. Wright; begun in 1886. March 4th, finished June 20th.

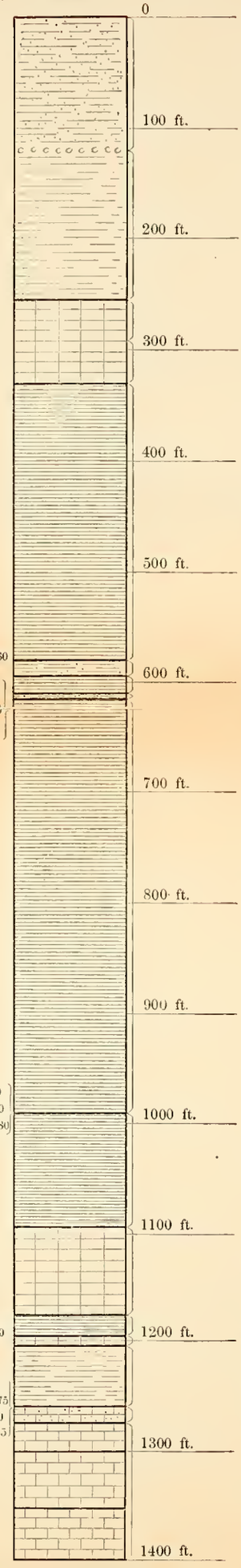
Local Names.	Equivalent Depths in Adjacent Wells.	Geological Column.	Total Depths.	Driller's (?) Record.
			0 Surface	
			100 ft.	1- 208 Surface, clay, etc.
			200 ft.	208- 293 Soft white shale.
			300 ft.	293- 313 Soft brown lime
Traverse or Hamilton			400 ft.	313- 513 Soapstone, soft, grey and sticky.
	(L. R.* 635 Port L. 710)		500 ft.	
Dundee Beds			600 ft.	
			700 ft.	
Monroe Beds			800 ft.	
			900 ft.	513-1280 Hard, mixed grey and brown limestone. (N. B. The records of this well do not show the distinction between limestone and dolomite; which I have therefore separated in the sketch according to records elsewhere.)
			1000 ft.	
			1100 ft.	
	(L. R. 1300)		1200 ft.	1180-1185 Yellow gypsum, (probably anhydrite).
	(2d Epoch)		1300 ft.	1280-1300 Hard, mixed grey and brown limestone.
				1300-1375 Blue shale; medium hard.
			1400 ft.	1375-1500 Grey, brown and white hard limestone.
	(3d Epoch)		1500 ft.	Rock salt.
				1500-1580 Shale and salt mixed; soft and hard.
			1600 ft.	1580-1605 Hard brown and white lime
				1605-1623 Rock salt.
				1623-1633 Hard grey lime.
				1633-1727 Salt.
			1700 ft.	1727 Hard limestone.

L. R. refers to Lester and Roberts' well at Marine City.
Port L. refers to Port Lambton well.

St. Clair Co., Alt. 600 ft. (?).
Algonac Salt Co. Depth 1614 ft. +
C. E. Wright.
Casing to 865 ft.; capacity 150 lbs. per day; also furnishes brine to Excelsior Salt Works.



Allegan Co., Alt. 708 ft.
Allegan Gas, Oil and Mining Co.
Julius C. Ellinger; samples examined by L.



Formations. Parallel Names in Ohio.	Local Names.	Equivalent Depths in Adjacent Wells.	Drillер's Record.		Sample Record.	
	Quaternary		1- 120	Sand and clay.		
			120	Gravel and flowing water.		
	Marshall ?			Struck slate and sandstone, end of drive pipe.	255	Impure grey banded sandstone.
					260	Pyritiferous bituminous coal.
					275	Siderite.
			292	Salt water.	295	Pyrite nodules and bluish shale.
			255- 331	Sandstone cased with 5⅝ inch pipe.		
					331	Brownish drab siderite, full of grains of calcite and pyrite, with traces of fossils.
		Charlotte 1150-1460	580- 595	Red rock.		Mixed red and green shale, calcareous red shale; residue of red clay, very little grit.
	Coldwater Shales	Muskegon 1200	595- 610	Blue shale.		Red, freely effervescing shale.
Waverly		Grand Rapids 1200	610- 615	Red rock again.	615	No effervescence, but turns from green to red with H Cl.
		Kalamazoo 710				
			615- 990	Grey shale; fine drilling.		No effervescence; greenish and bluish gray shales.
		Charlotte 1700				
		Kalamazoo 1070				
		Benton Harbor 280	990-1095	Black shale.		Burns on heating; bituminous shale.
Huron Shale	St. Clair Black Shales		1095-1175	Hard rock; salt water between 1120 ft. and 1200 ft.		Siderite. $FeCO_3$. This may be merely a large nodule.
			1175-1195	Black rock or slate.		Bituminous black shale.
		Kalamazoo 1200	1195-1205	Limerock.		Mixture of dolomite and black shale.
Hamilton	Traverse		1205-1260	Blue shale.	1205-1260	Greenish or bluish grey shale, slowly effervescing.
		Charlotte 1985	1245	Oil; crust very hard; turned drill.		
		Grand Rapids 1775	1264	Oil.	1260-1264	Also a piece shot out.
		Kalamazoo 1270	1275	Bottom of No. 1.	1275	Sandy limestone, light buff.
		Benton Harbor 665			1275-1300	
Upper Helderberg	Dundee				1300-1350	These three alike, light yellow limestones, rapidly effervescing, containing white chert and fragments of darker grey pyritiferous seams; also brachiopod fragments (?), either Leptocaelia acutiplicata or Spirifera gregaria.
					1350-1400	

Alpena Co., Alt. 609 ft. (Near Bed of Thunder Bay River.)
Depth 1025 ft.
Rominger, III, p. 39 et seq.
C. E. Wright (?).

Local Names.	Equivalent Depths in Adjacent Wells.	Geological Column.	Total Depths.	Driller's (?) Record.	
			About 20 ft. Partridge Point Beds.	Limestone and fossilliferous bluish or greenish shales.	Exposed Section Rom., III, 41 to 44.
			About 60 ft. Stony Point Beds.	Light colored limestone with Stromatopora growing darker, then lighter.	
			Surface		
			100 ft.		
Traverse or Hamilton			200 ft.	1- 400 Limestone.	
			300 ft.		
			400 ft.		
	F.* 1070 Frankfort F. 1230			400- 480 Blue shale beds. } (Hamilton, cf. Rominger, with well marked fossils.)	
			500 ft.		
Dundee Limestone				480- 600 Limestone; variable hardness and color.	
			600 ft.		
			700 ft.		
Monroe or Lower Helderberg			800 ft.	600-1025 Limestone; dolomitic; light colored = Helderberg, Rominger.	
			900 ft.		
			1000 ft.	Salt	

* F. refers to well at Frankfort.

Bay Co.; 116. 5192 ft.
Bored by John Mason.
Depth 2805 ft., or from Wright's notes in one other place, 2209½ ft.
C. E. Wright and Bay City Tribune in 1885-86.

Local Names Correlation by Lane.
Equivalent Depths in Adjacent Wells.
Formations, Parallel Names in Ohio.
Geological Column.
Total Depths.
Driller's Record.

0
100 ft.
200 ft.
300 ft.
400 ft.
500 ft.
600 ft.
700 ft.
800 ft.
900 ft.
1000 ft.
1100 ft.
1200 ft.
1300 ft.
1400 ft.
1500 ft.
1600 ft.
1700 ft.
1800 ft.
1900 ft.
2000 ft.
2100 ft.
2200 ft.
2300 ft.
2400 ft.
2500 ft.
2600 ft.
2700 ft.
2800 ft.

0 - 81 Sand and clay.
81 - 120 Hard pan.
120 - 170 Blue shale.
170 - 300 Sandy shale.
300 - 345 Limerock to Lime
345 - 635 Sandrock, lime 11 ft. to M. H.
635 - 660 Sandy shale
660 - 701 Blue shale.
701 - 712 Gypsum; little 6 in. coring to 722.
712 - 820 Blue shale.
839 - 850 Hard limerock.
850 - 870 Sandstone; brine to 1012 Napoleon.
870 - 891 White shale.
955 - 1005 Red shale.
1005-1105 Blue shale.
1105-1115 Limestone
1145-1220 Hard blue shale.
1238-1255 Blue limestone.
1255-1300 White shale.
1370-1510 Sand shale.
1500-1520 Blue shale.
1520-1540 Hard limestone.
1540-1610 Blue shale.
1618-1638 White shale.
1638-1833 Black shale
1833-1898 Black limestone
1898-1915 Brine-bearing sandstone.
1915-1963 White shale.
1963-2003 Hard limestone
2003-2043 Soft black sand
2048-2091 Hard blue shale at 2067
2091 Black oily shale, 15-20 ft. thick.
2093-2113 Very hard limestone, 6½ in. base to 21.50 and 8½ in. to low.
2110-2133 Sandstone.
2133-2141 Grey limestone 2140 Pumped clean sand.
2141-2200 Sandrock with salt brine bed, no refusing top.
2200 ft. deep stopped in blue shale
2300 ft.
1120 Below sea level.
2300-2361 White shale.
2371-2383 Black oily sandy shale.
2600 ft.
2661-2683 Black hard limestone.
2700 ft.
2695-2715 Grey limestone.
2800 ft.
2778-2803 Blue shale, quite hard.
2797-2805 Sandy limestone, LIME Basin.
2805-2863 Limestone

Jackson Coal Group
Pocono ?
Grand Rapids
Marshall
Coldwater Shale
Berea Shale
Richmondville
Jackson 1358-1410
Pontiac 808
St. Clair
Pontiac 965
Traverse
Dundee
Pontiac 1291?
Marcellus
Corniferous

SHALE
LOGAN SERIES
SANDSTONE
COAL
WAVERLY
CUYAHOGA SHALE
BEREA SHALE
BEREA GRIT
ERIE
HURON
HAMILTON

Bay City 198

BENTON HARBOR. No. 1.

Berrien Co. Alt. 600 ft.
Benton Harbor Natural Gas and Oil Co. Depth 1205 ft.
Samples from Fred. Jordan; C. E. Wright, Dr. Rockwell.

Local Names.	Equivalent Depths in Adjacent Wells.	Formations. Parallel Names in Indiana.	Geological Column.	Total Depths.	Driller's Record.	Sample Record.
		BEDFORD SHALE		100 ft.	135	Bluish grey argillaceous shale.
					135- 150	Red shale { Chocolate brown shale, ef. in cold HCl; 70 per cent residue. Under microscope, fine fringy argillaceous mass and small granules; does not depolarize the light.
	Constantine 301				150- 170	Light blue shale; quite hard; effervesces slightly; large residue, finely granular, apparently isotropic.
		ERIE		200 ft.		
					170- 280	Blue shale or slate (?). No sample.
St. Clair Shale	Constantine 492			300 ft.		
		HURON			280- 475	Black shale or slate.
				400 ft.		
	Constantine 703			500 ft.		
Traverse, Hamilton		HAMILTON			475- 640	Argillaceous limestone; dark blnish drab; contains iron pyrites; brisk effervescence; 50 per cent residue of a fringy clay mass.
				600 ft.		
	cf. S. B. 455*				640-665	Calcareous argillaceous shale; dark drab; medium hard; brisk ef; 70 per cent residue of clay.
		ORISKANY			665- 700	Arenaceous limestone; dark drab; brisk ef.; 20 per cent residue of rounded glassy grains of sand.
				700 ft.	700- 706	Limestone, greyish white mixed with dark drab; brisk ef.; 10 per cent residue, mainly isotropic.
					706- 711	
					711- 720	Porous limestone; light grey; brisk ef.; 2 per cent residue of a finely granular mass.
					720- 725	Greyish limestone; brisk ef. in cold acid, 10 per cent residue of round glassy grains of sand (and bits of green shale; no anhydrite.)
Dundee or Upper Helderberg	cf. S. B. 455				725- 735	
					735- 741	
					741- 750	Dark drab to light drab limestone; brisk ef.; 5 to 10 per cent residue of rounded grains of sand.
					750- 755	755- 764
					764- 778	Light grey limestone; brisk ef.; 2 to 8 per cent residue of rounded glassy grains of sand.
					778- 788	Brisk effervescence.
				800 ft.	788- 800	Limestone; drab; brisk ef.; 20 per cent residue of sand and gypsum.
					800- 806	
					806- 815	
					815- 820	Marly gypsum; very light grey; 80 per cent residue of anhydrite and a few grains of silica.
					820- 832	
					832- 846	Dolomitic limestone; drab; resembles sand; slight ef in cold acid; 10 per cent residue of rounded glassy grains of sand, anhydrite and gypsum.
					846- 858	
					858- 900	
Monroe		HELDERBERG		900 ft.		
					940	(Like 900-1205. L.)
					900-1205	Dolomite; slow ef. in cold acid; 3 to 20 per cent residue of grains of greyish sand.
				1000 ft.		
Niagara				1100 ft.		
				1200 ft.		

ABBREVIATIONS.

Ef.=Effervescence.
HCl.=Muriatic Acid.
***S. B.=Well at South Bend, Ind.**

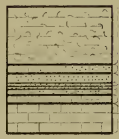
Eaton Co., Alt. 800 ft.
Depth 2200 ft.
E. Shepard and F. W. Higby. Cf. Rominger, III, 130 and 131; also the Hillsdale well.
Samples examined by Lane.

Depth Above or Below Sea Level.	Local Names.	Equivalent Depths in Adjacent Wells.	Geological Column.	Total Depths.	Sample Record.
324					Surface.
+ 252	Woodville or Parma Sandstone			100 ft.	72- 160 Fine sandrock. S. Mainly quartz sand, with a very little calcite and larger bits of dark bluish grey shale.
+ 164	Jackson Coal Measures ?			200 ft.	160- 370 Fine shale. S. Quite dark bluish, with black specks, (fossiliferous?), very finely divided quartz, much clayey matter and but a trace of calcite.
				300 ft.	
-46	Grand Rapids Group			400 ft.	370- 570 Fine sandrock. S. A somewhat sandy, medium *grey shale;* no reaction for gypsum; a trace of calcareous matter. There are some fragments very fine-grained, but quite gritty.
				500 ft.	
-246	Marshall Sandstone			600 ft.	570- 680 Soft sand. S. Fine grained; quite *calcareous;* greenish grey *sandstone*, showing under the lens distinctly the rounded grains of colorless quartz. One larger piece shows distinctly the greyish or greenish white sandstone, with the rounded quartz-sand and occasional specks of mica.
-356				700 ft.	
				800 ft.	680-1000 Shale and sand. S. *Argillaceous limestone*, with a little quartz and green earth; greenish grey.
				900 ft.	
-676				1000 ft.	1000-1150 Shale and sand. S. Much like the preceding 320 ft. *Calcareous shale*, effervescing briskly.
				1100 ft.	
-826	Coldwater Shales			1200 ft.	
		Manistee 715-875		1300 ft.	1150-1460 Soft sand. S. Much of the matter greenish grey argillaceous, as in previous samples, but there are also larger fragments of siderite or *dolomite*, often brownish. These may represent nodules of kidney iron ore.
				1400 ft.	
-1136					
-1176				1500 ft.	1460-1500 Sand and shale. S. Somewhat sandy limestone; contains some brown and white mica.
				1600 ft.	1500-1660 Soft shale. S. Calcareous shale with traces of quartz.
-1336	Richmondville or Berea	Jackson 1344-1400 Grand Rapids 1175			1660-1680 Hard sand. S. Gritty calcareous shale. { In the whole preceding section there is no distinct break.
-1376				1700 ft.	1680-1700 Red rock. S. *Calcareous red shale;* gritty; ferruginous.
	St. Clair or Ohio Shale			1800 ft.	1700-1900 Shale. S. *Black shale*, with occasional harder reddish fragments, barely calcareous.
-1576				1900 ft.	1900-1930 Shale. S. Brownish black *bituminous shale*, non-calcareous; burns with an aromatic smoke.
-1626	Traverse or Hamilton Group				1930-1950 *Shale.* S. Shows frequent pyrite; black bituminous and grey grains, slightly calcareous.
					1950-1980 Shale. S. Grey calcareous shale with bits of calcite from fossils.
-1661		Jackson 1770		2000 ft.	1980-1985 Shale and lime. S. Highly fossiliferous shale full of bits of brachiopods (?) and of black matter. 1985-2000 Top of limestone. S. Grey limestone, briskly effervescing.
	Dundee or Upper Helderberg				2000-2050 Brine { Sp. wt. 1.198. Salin. 91°. } Limestone. S. Salt brine (Sp. wt. 1.198=97 per cent) at 2050; effervesces briskly, with a cherty residue and a little quartz. All these limestones down to 2121 ft. are *yellowish* or *buff*, ferruginous with magnetite.
				2100 ft.	2050-2085 Limestone. S. Effervesces very briskly.
-1781	Monroe or Beginning of Lower Helderberg (?)				2085-2100 Limestone. Acid water in it. S. Effervesces briskly; residue of cherty dolomite, quartz, magnetite and pyrite. 2100-2102 Limestone; hard water under it. S. Effervesces briskly; residue of chert, quartz, green grains, with iron rust, magnetite and pyrite. 2100-2105 Limestone. S. like previous sample, residue larger. 2105-2121 Limestone. S. damp, reacts faintly for sulphates (gypsum), like previous sample.
					2121-2150 Limestone. S. Buff to grey, with little fragments of iron ore in thin seams (hematite; magnetite), but little quartz and no chert.
1885				2200 ft.	2150-2200 Limestone. S. Buff to grey; slight residue of chert and quartz.

ABBREVIATIONS.— S. Sample.

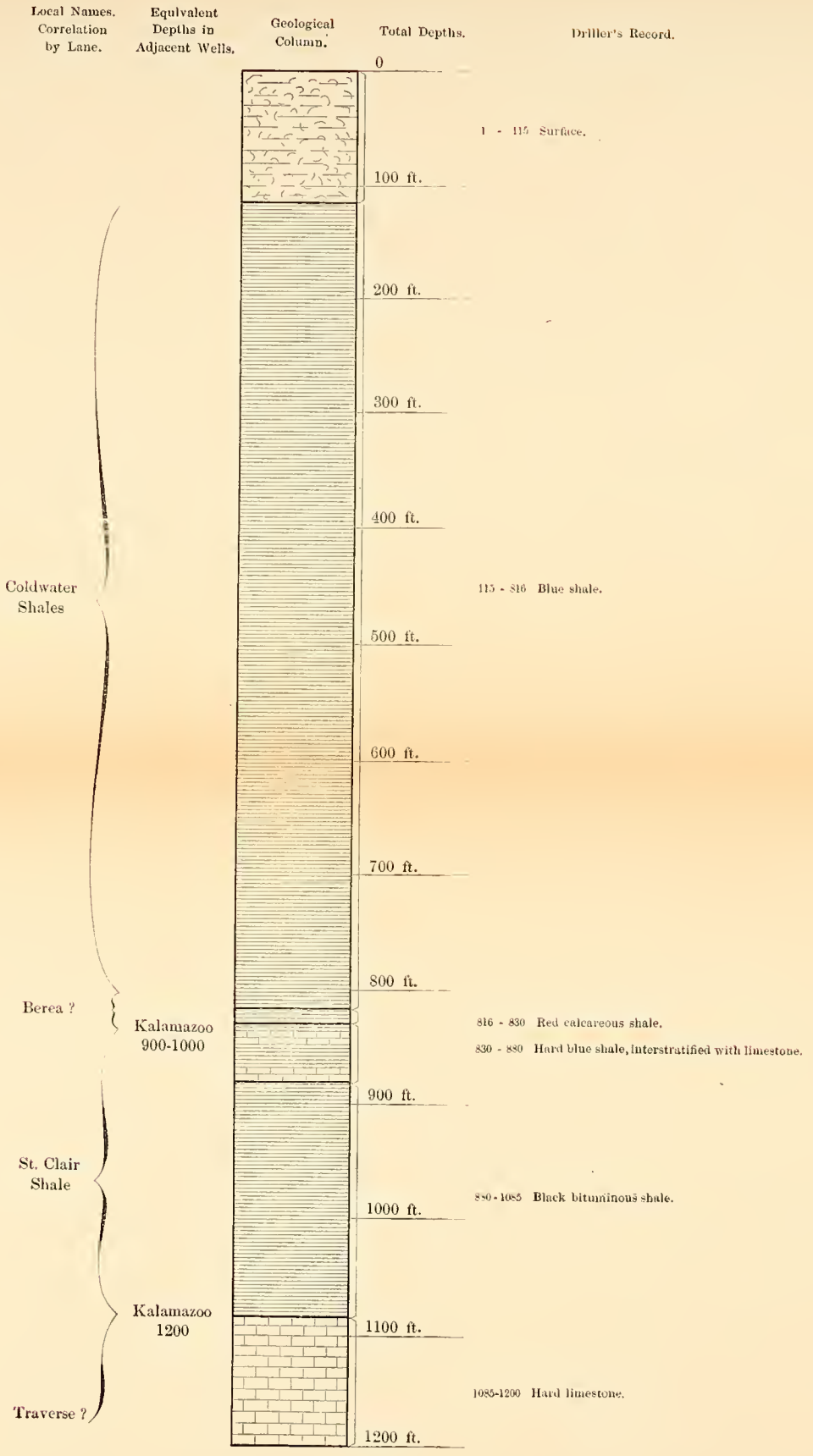
CLIFFORD.

Lapeer Co., (or is it Canada? L.) Alt. 840 ft.
Clifford Oil Co. Depth 120 + ft.
C. E. Wright. July 24th, 1887.



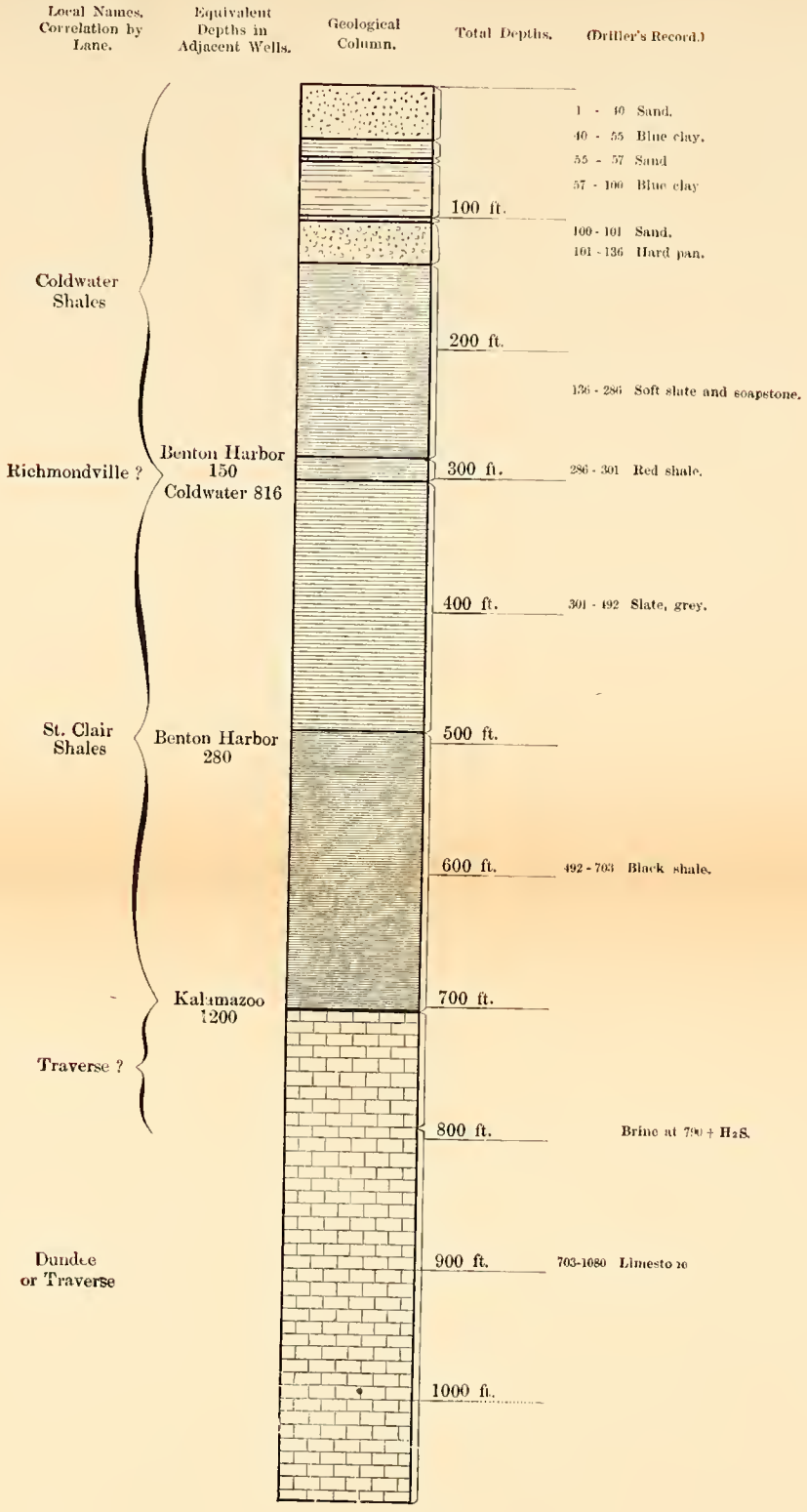
Geological Column.	Total Depths.	Driller's Record.
	1 - 55	Surface.
	55 - 63	Blue sandstone.
	63 - 74	Red Sandstone.
	74 - 75¼	Coal and rotten rock.
	75¼ - 78½	White quartz.
	78½ - 85	Loose rock of flint; copper, iron pyrites and streak of lead.
	85 - 92	Flinty limestone, red.
	92 -120	Blue limestone.

Branch Co., Alt. 983 ft.
Dr. J. H. Bennett. Depth 1200 ft.
C. E. Wright.



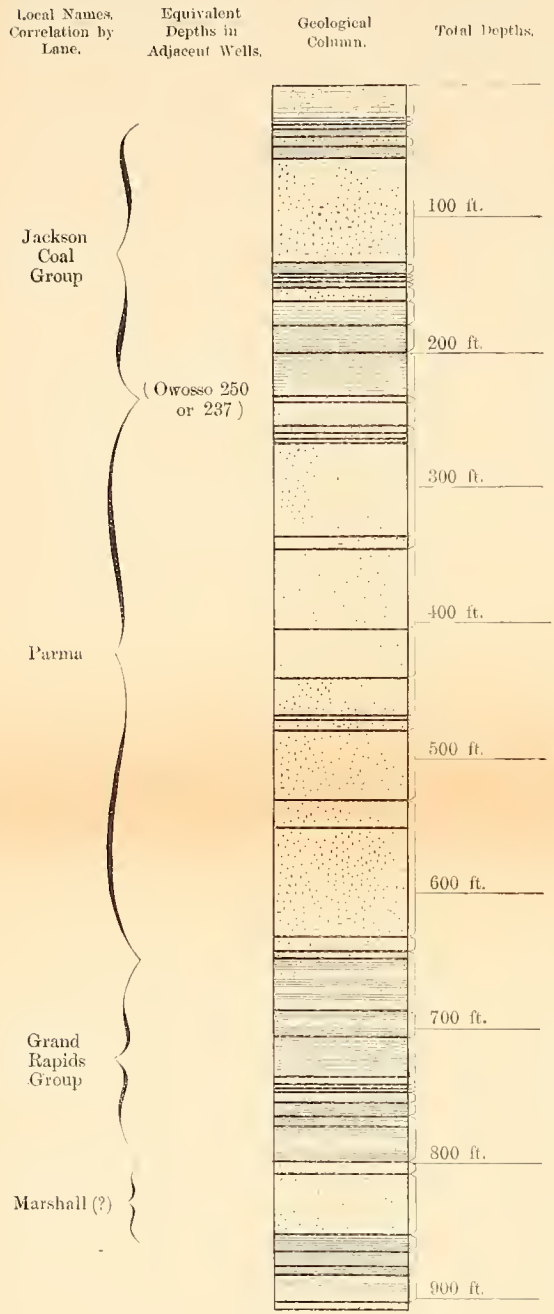
CONSTANTINE.

St. Joseph Co. Alt. 803 ft.
Levi Dodge. Depth 1080 + ft.
C. E. Wright; correlated by Lane.



CORUNNA. No. 3.

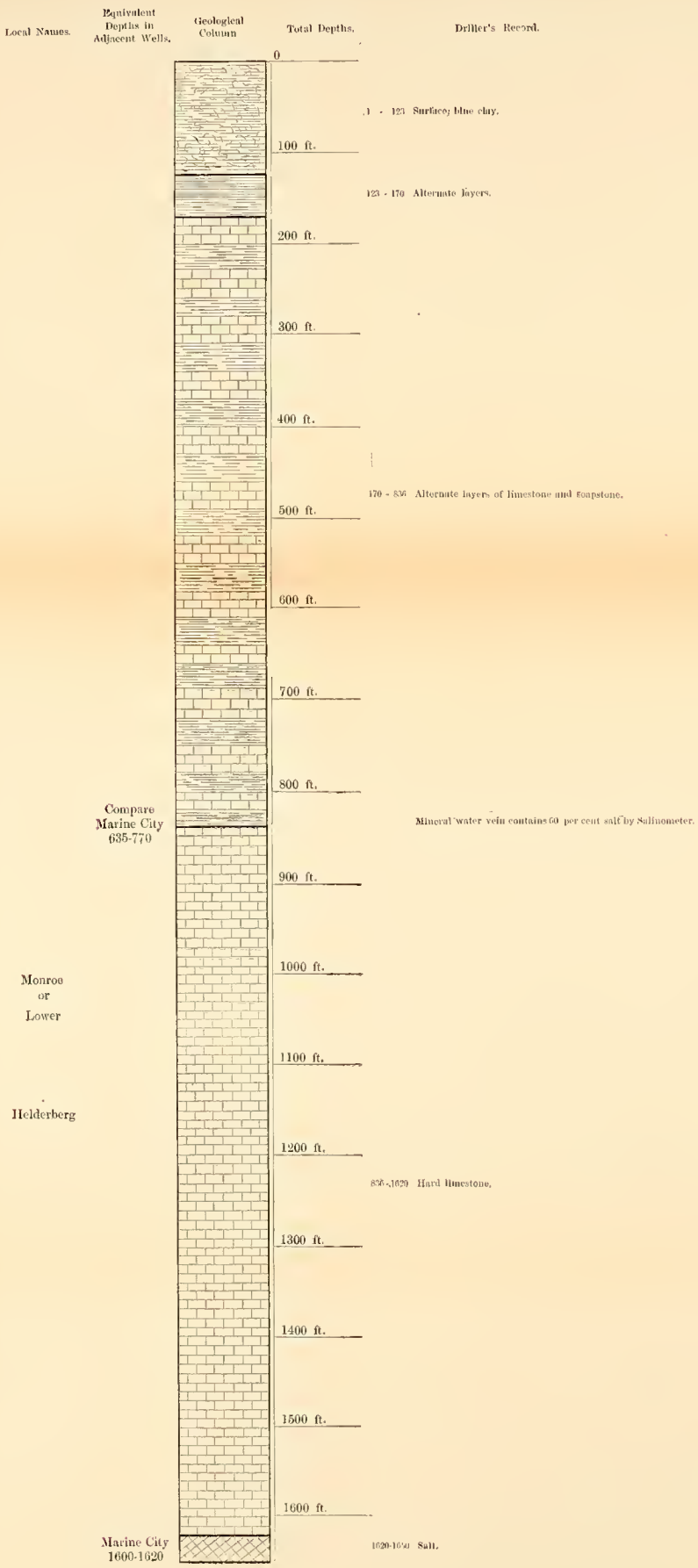
Shiawassee Co. Alt. 776 ft.
Corunna Coal Co., located near the center of the S. side of the E. ½ N. W. ¼, S. 22, T. 7, N., R. 3, E. Depth 907 ft.
Drilled by O. J. Davids; finished January 7, 1885.
Test-hole for the lower strata of coal. It is possible that the whole series is really in the coal group.



Driller's Record.

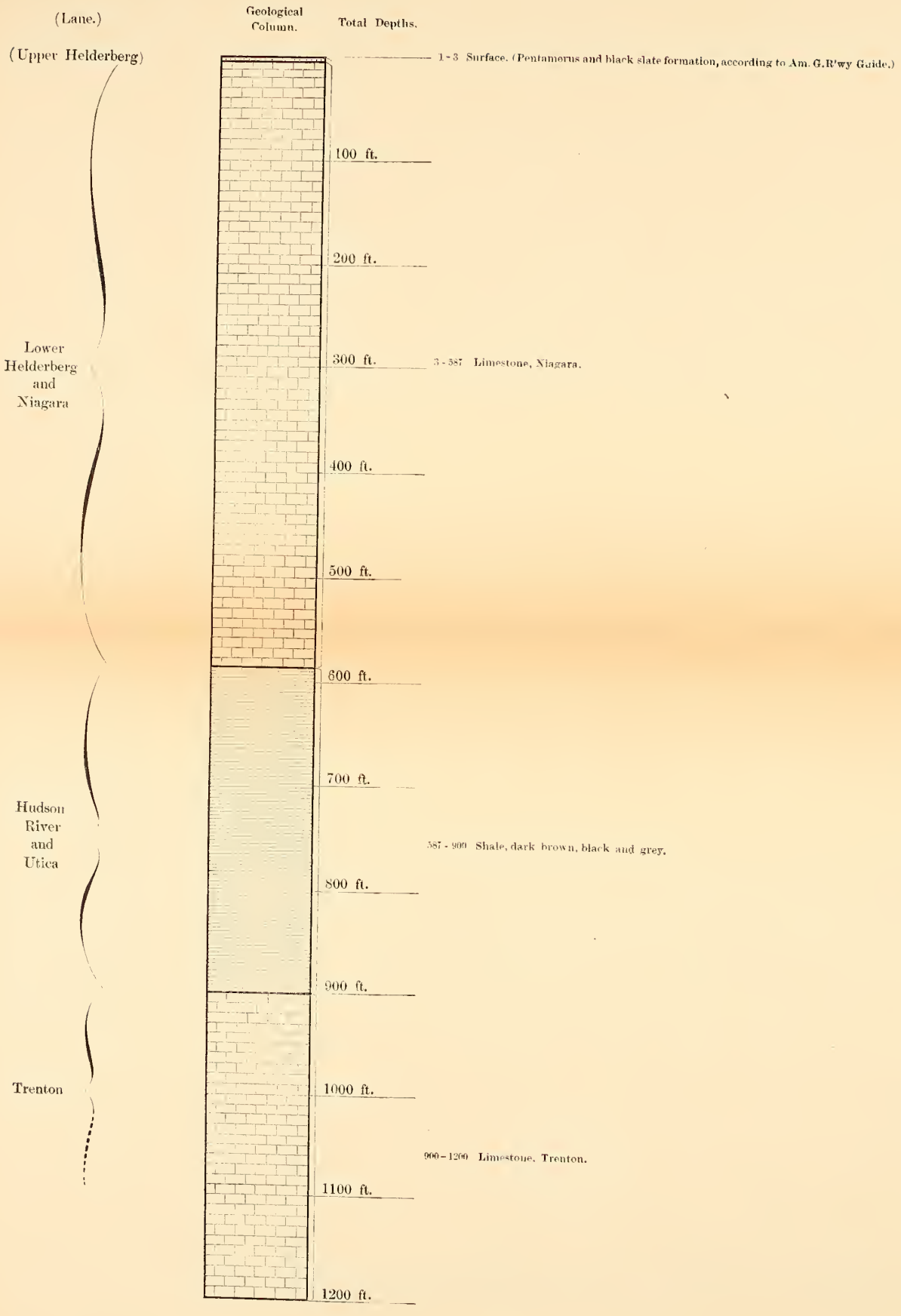
1	- 26½	Surface, sand and clay.	
26½	- 28	Quicksand.	
28	- 30	Light slate.	
30	- 33	Dark slate.	
33	- 40	Fine clay.	
40	- 48	Sand rock.	
48	- 55	Black slate.	
55	-135	Sand rock.	
135	-143	Black slate.	
143	-144	Blue shale.	
144	-147½	Sand rock.	
147½	-152	Blue shale.	
152	-161	Sand rock.	
161	-180	Blue slate.	
180	-200	Grey shale, fine.	
200	-231	Blue slate.	
231	-238	Sand rock.	
238	-255	Blue sand rock.	
255	-260	White sand rock.	
260	-266	Sand rock.	
266	-268	Blue sand rock.	
268	-337	White sand rock.*	*(It is very doubtful if all this is really quartz sand; some of it is possibly dolomite. L.)
337	-344	Bastard sand rock.	
344	-407	Sand rock.	
407	+441	Light grey sand rock.	
441	-471	White sand rock.	
471	-472	Dark sand rock.	
472	-480	White sand rock.	
480	-531	Blue sand rock.	
531	-551	Common sand rock.	
551	-631	Blue sand rock.	
631	-643	Blue hard sand rock.	
643	-649	Common sand rock.	
649	-688	Alternate layers, sand rock and blue slate.	
688	-706	Slate and sand rock.	
706	-738	Blue slate.	
738	-743½	Sandstone.	
743½	-744	Black Slate.	
744	-745	Slate.	
745	-755	Sand rock.	
755	-765	Slate.	
765	-778	Sand rock and blue slate.	
778	-800	Sand rock and blue slate.	
800	-809	Dark sand rock.	
809	-852	Sand rock.	
852	-864	Black slate.	
864	-878	Slate.	
878	-883	Grey slate.	
883	-903	Slate and sand rock.	
903	-907	Lean sand rock.	

Ontario. Alt. 630 ft. (?).
J. J. Carter. Depth 1650 ft.
One-half mile due east from St. Clair, on the other side of the river.
C. E. Wright.

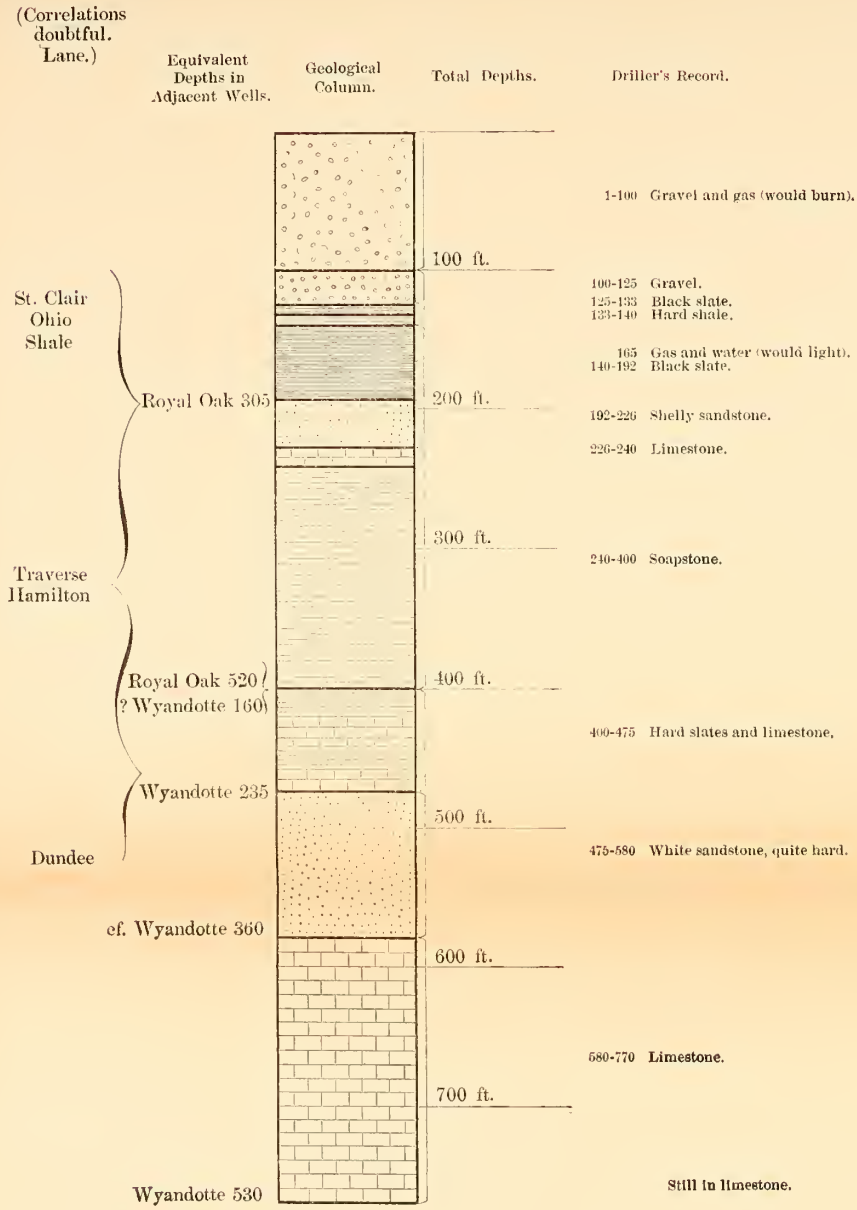


DELPHI.

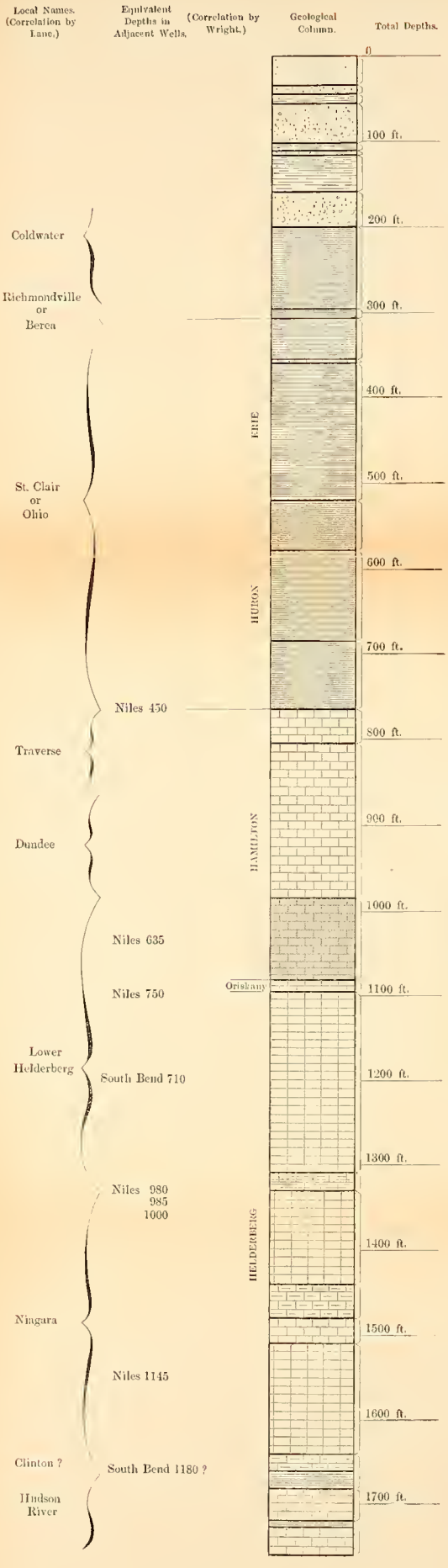
Carroll Co., Indiana. Alt. 600 ft. (?).
Depth 1200 ft.
C. E. Wright, from Levi Dodge, Constantine, Michigan.



Wayne Co. Alt. 581 ft. to 634 ft.
Detroit Natural Gas Co., Fred. W. Hayes, Sec. and Treas. 7 M. N., and 3 E. of Jefferson Ave. Depth 770 ft
Frank E. Snow.



Cass Co. Alt. 760 ft.
Round Oak Gas and Fuel Co. Depth 1760 ft.
C. E. Wright; Samples with the State Survey.
Drilled July 6th, 1887, by Will. M. Furr.

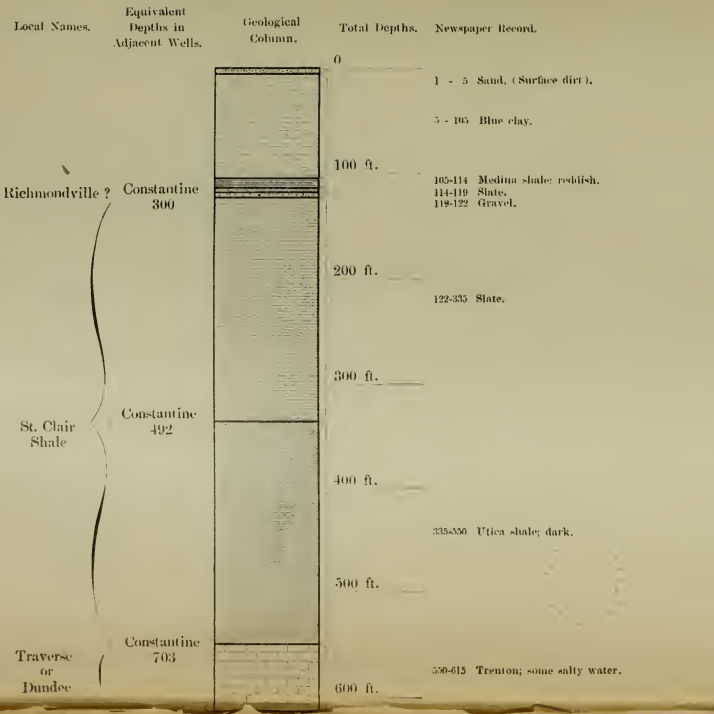


0- 34		Sand, fine and coarse.
34- 41		Gravel.
44- 56		Blue clay.
56- 103		Sand and some gravel.
103- 111		Blue clay.
111- 115		Coarse gravel.
115- 159		Blue clay, very tough.
159- 200		Sand and gravel, coarse and fine
200	S.	
275	S.	Blue argillaceous shale; slow effervescence in acid.
282	S.	
		Red argillaceous shale; slow effervescence in acid, 12 ft.
330	S.	Argillaceous shale; light blue, with streaks of hard blue sandstone; slow effervescence in acid; 90 per cent residue.
343	S.	
		Argillaceous limestone; very hard.
435	S.	Argillaceous shale; bluish drab; slow effervescence; 95 per cent residue in acid.
565	S.	Sandy shale; dark bluish drab; hard and soft; slow effervescence; 90 per cent residue.
640	S.	Argillaceous shale; dark drab and brown, quite soft; slow ef.; 95 per cent residue, clay.
650	S.	Argillaceous shale; dark brown, hard and soft, slow effervescence; 90 per cent residue, clay.
670	S.	Argillaceous shale, dark brown, medium hard.
765	S.	Brown argillaceous shale, burning with an aromatic smell.
809	S.	Argillaceous limestone, dark drab, brisk ef. in cold acid; 10 to 15 per cent residue of clay.
865	S.	Limestone, dark drab, c. g., brisk ef. in cold acid; 2 per cent residue of angular grains of silica.
868	S.	Limestone, dark drab, c. g., brisk ef. in cold acid; 2 per cent residue of angular grains of silica.
Salt 871	S.	Limestone, light grey, f. g., brisk ef. in cold acid; 5 per cent residue of angular grains of quartz and silica.
Brine 100°		
904	S.	Limestone, light grey, f. g., brisk ef. in cold acid; 4 per cent residue of angular grains of quartz and silica.
920	S.	Limestone, light grey, f. g., brisk ef. in cold acid; 1 per cent residue of silica.
950	S.	Limestone, dark drab, c. g., brisk ef. in cold acid; 4 per cent of dark brown residue of silica and carbon.
965	S.	Limestone, dark drab, f. g., brisk ef. in cold acid; 5 per cent of dark brown residue of silica and carbon.
975	S.	Limestone, light drab, f. g., brisk ef. in cold acid; siliceous residue.
980	S.	Limestone, brownish drab, m. g., brisk ef. in cold acid; 5 per cent siliceous residue.
985	S.	
995	S.	
1001	S.	Gypseous dolomite, dark grey, m. g.; 25 per cent residue of gypsum, anhydrite and silica.
1010	S.	
1020	S.	Gypseous dolomite, drab, f. g., brisk ef.; 30 per cent residue of gypsum, anhydrite and silica.
1030	S.	1035 S.
1038	S.	Gypseous dolomite; drab, f. g., brisk ef.; 10 per cent residue of gypsum, anhydrite and silica.
1050	S.	1055 S.
1060	S.	Gypseous dolomite; drab, f. g., brisk ef.; 25 per cent residue of silica, gypsum and anhydrite.
1065	S.	
1080	S.	Gypseous dolomite; light grey, f. g., brisk ef.; 12 per cent res. of gypsum, anhydrite and cherty silica.
1083	S.	1090 S. 1092-1095 S.
1100	S.	Arenaceous limestone, light grey, f. g. brisk ef.; 4 to 12 per cent res. of rounded grains of glassy sand, quartz and flint.
1107	S.	
1115	S.	
1120	S.	1125 S.
1135	S.	
1140	S.	(Dolomitic) limestone, light grey, f. g.; 3 to 5 per cent residue of quartz, flint and pyroxene (?).
1160	S.	
1160	S.	(Dolomitic) limestone, light grey, f. g.; 7 per cent residue of chert, quartz and pyroxene (?).
1175	S.	Limestone, light grey; 5 per cent residue of chert, quartz, pyroxene and anhydrite.
1185	S.	1195 S.
1200	S.	(Dolomitic) limestone, light grey; 1 per cent residue of chert, quartz, pyroxene and anhydrite.
1210	S.	
1220	S.	Limestone light grey; 1 per cent residue of chert, quartz, pyroxene and anhydrite.
1240	S.	Limestone, light grey; 1 per cent residue of chert, quartz, pyroxene and anhydrite.
1265	S.	(Dolomitic) limestone, light grey; $\frac{1}{2}$ per cent residue of chert, quartz, pyroxene and anhydrite.
1275	S.	Limestone, light grey; 15 per cent residue of clay.
1290	S.	
1310	S.	1315 S.
1320	S.	Argillaceous limestone, drab, f. g., brisk ef. in cold acid; 20 to 30 per cent residue of clay.
1325	S.	
1330	S.	(Dolomitic).
1335	S.	1340 S.
1350	S.	Limestone, grey; brisk ef. cold acid; 1 to 2 per cent res. of rounded glassy grains of sand and angular ones of flint
1370	S.	
1384	S.	(Dolomitic).
1390	S.	
1395	S.	
1400	S.	Limestone, grey; brisk ef. in cold acid; 2 per cent residue of rounded glassy grains of sand and angular ones of flint.
1434	S.	(Dolomitic limestone).
1453	S.	Marly limestone, creamy grey, very brisk ef. in cold acid; 8 per cent residue of silica and clay.
1475	S.	
1480	S.	
1492	S.	Limestone, creamy grey, f. g., brisk ef.; 1 per cent residue of rounded grains of glassy sand and angular ones of flint and anhydrite.
1518	S.	(Dolomitic) limestone, creamy grey, f. g., brisk ef.; ½ per cent res. of rounded grains of glassy sand and angular ones of flint and anhydrite.
1525	S.	
1540	S.	
1550	S.	Limestone, greyish white, f. g., brisk ef.; 5 per cent res. of rounded grains of glassy sand and angular ones of flint and anhydrite and clay.
1580	S.	Limestone, greyish white, f. g., brisk ef., 2 per cent res. of rounded grains of glassy sand and angular ones of flint and anhydrite and clay.
1610	S.	(Dolomitic) limestone, grey, f. g., brisk ef.; 5 per cent residue of silica and clay.
1620	S.	1625 S.
1640	S.	(Dolomitic).
1645	S.	
1660	S.	Marly limestone, creamy white; 1 to 8 per cent res. of rounded grains of sand, clay and anhydrite.
1665	S.	
1670	S.	
1680	S.	Argillaceous shale, bluish drab, slight ef.; 95 per cent residue of clay.
1690	S.	
1695	S.	
1700	S.	Argillaceous limestone, dark drab, brisk ef.; 10 to 15 per cent res. of clay and some dark flint.
1720	S.	Black carbonaceous argillaceous shale, blue black, slow ef.; 95 per cent residue of clay.
1728	S.	
1730	S.	
1750	S.	
1753	S.	
1760	S.	Carbonaceous limestone, brownish red to yellowish grey, brisk ef. in cold acid; 10 to 20 per cent residue of rounded glassy grains of sand, white chert and anthracite.

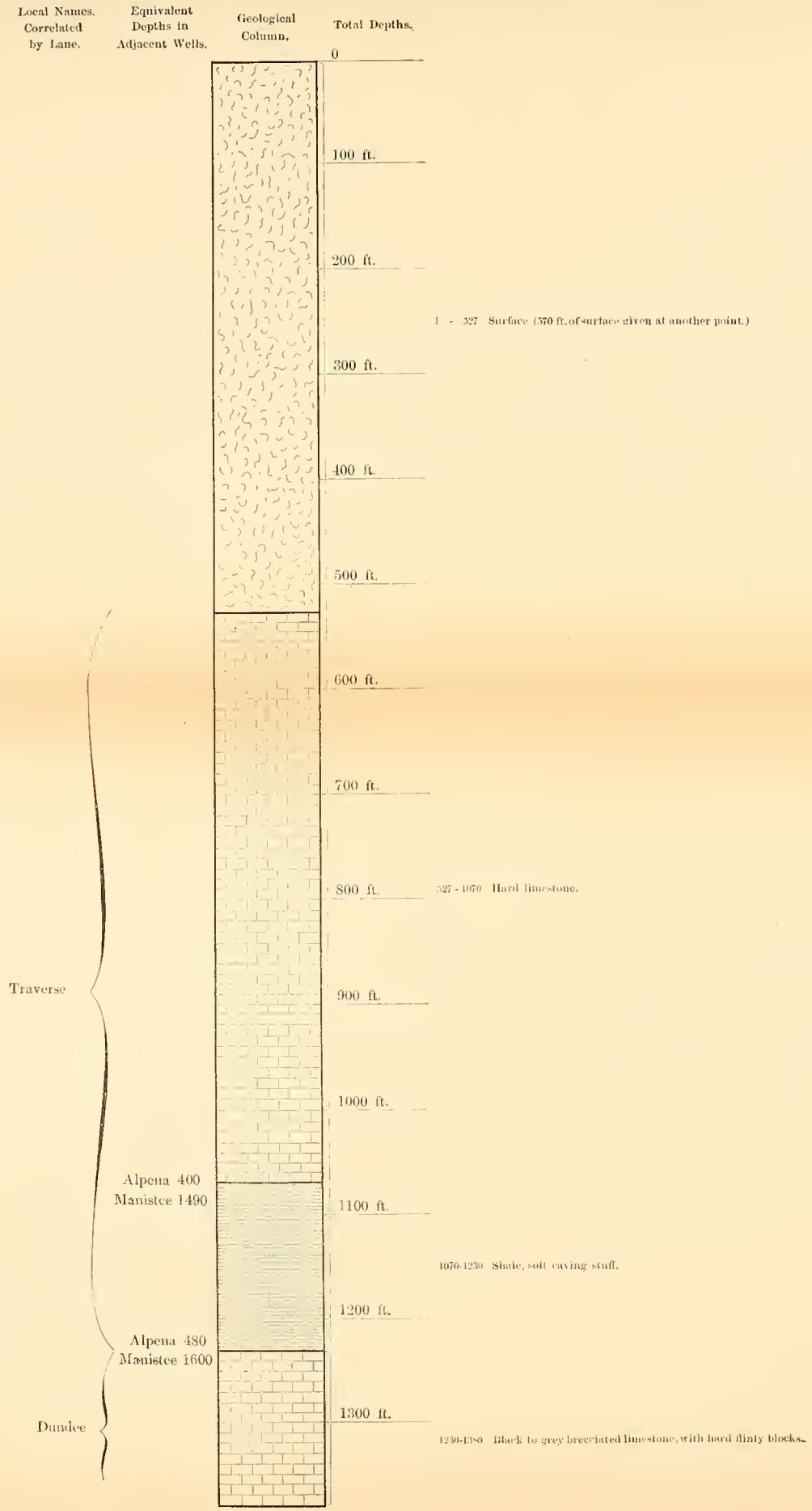
ABBREVIATIONS.

Ef. = Effervescence.
C. G. = Coarse grained.
M. G. = Medium grained.
F. G. = Fine grained.
Res. = Residue.
S. is placed after points from which samples are taken.

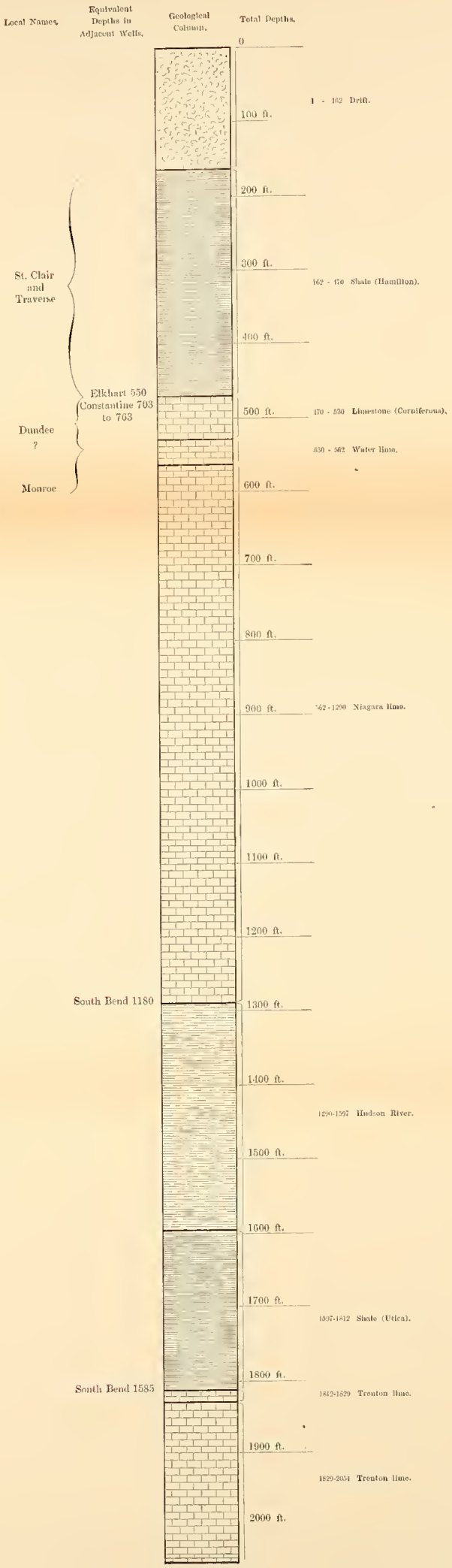
Elkhart Co., Indiana. Alt. 755 ft. or 741 ft.
Depth 615 ft.
Newspaper cutting, letter from Chas. A. Thompson, Adamsville, Cass Co., Mich., to C. C. Allison, Esq.



Benzie Co., Alt. 600 ft.+
A. G. Butler. Depth, about 1800 ft.
C. E. Wright and Mr. Percy.



Depth 2054 ft.
Sorby, State Geologist of Indiana (?), acc. to C. E. Wright.

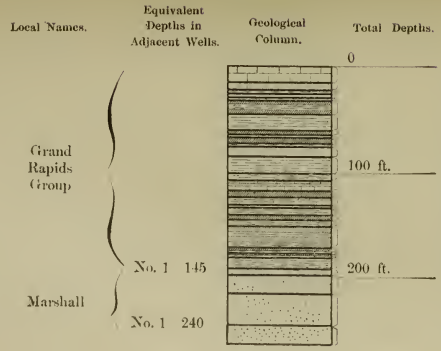


Kent Co. Alt. 605 ft. to 630 ft.
Grand Rapids Artesian Well Co. Depth 2220 ft.
C. E. Wright.

Local Names. Correlated by Lane.	Equivalent Depths in Adjacent Wells.	Total Depths.			Driller's record.
		0			
Grand Rapids Group			1- 10	Drift.
			10- 51	Black clay slate.
		100 ft.	51- 128	Plaster rock mixed with clay slate.
			128- 145	Sandstone, dark and light colored.
Marshall Sandstone		200 ft.	145- 240	Sandstone, light grey. Fresh water, increases with depth.
			240- 259	Hard black coarse sandstone. Increase of fresh water.
			259- 271	Blue clay slate
		300 ft.		
			271- 400	Ash-colored sandstone, mixed with clay seams and layers of soapstone; fine texture. Small quantity of weak brine, 20°.
	Muskegon 325	400 ft.		
			400- 420	Sandy shale at top and clay-rock boulders and sheets below.
		500 ft.		
			420-1155	Light blue to ash-colored shale, with very little change in color except for short places which are little darker. Quite uniform as to hardness. Except these 2?, the lower 250 ft. has more hard streaks and boulders than it could make slate-drills.
		600 ft.		
		700 ft.		
Coldwater Shales			702- 712	Dark hard water-lime.
			712- 722	There is a streak of ten feet from 712 to 722 of calcareous water-lime, dark and hard at top and softer below; but it is all hard rock
		800 ft.		
		900 ft.		
		1000 ft.		
		1100 ft.		
Richmondville or Bereа	[Jackson 1338] Kalamazoo 710	1200 ft.	1155-1175	Dark red clay; soft.
			1175-1205	Sandstone; brine 2°, small amount.
		1300 ft.		
			1205-1500	Light to greenish blue shale, mixed with clay rock. Streaks and boulders and streaks of gas-scented material.
St. Clair		1400 ft.		
	Muskegon 1400 Bereа ?	1500 ft.		
		1600 ft.	1500-1708	Black slate rock; scent of gas at top and stronger in depth and very strong at bottom.
		1700 ft.		
			1708-1775	Black slate or hard rock; strong odor of gas and oil.
Traverse ?		1800 ft.	1775-1827	Drab limestone; color changes nearly every foot. Supposed to be Corniferous.
			1827-1855	Drab magnesian limestone.
			1855-1865	Very dark water-lime.
			1865-1885	Each screw changes color.
Dundee		1900 ft.		
		2000 ft.	1885-2061	Limestone; light grey and medium hard in upper portion and dark drab and hard below.
Monroe		2100 ft.		
	Muskegon 2000 Kalamazoo 1600	2200 ft.		Gas, marl, limestone and brine.

GRAND RAPIDS, No. 2.

Hon. L. Lyon. Depth 265 ft.



0- 14 Hard grey limerock.
14- 20 Yellow sandrock; fresh water.
20- 22 Blue clay. 22-27 Coarse reddish sandrock. 27-30 **Blue clay.**
30- 41 Clay slate with layers of gypsum.
41- 59 Clay slate.
59- 63 Gypsum.
63- 65 Clay slate.
65- 71 Gypsum.
71- 74 Clay slate.
74- 82 Bluish sandrock, hard.
82-100 Bluish clay rock. Saline.
100-107 Sand and clay rock.
107-117 Limestone and gypsum.
117-124 Gypsum.
124-133 Clay slate.
133-138 Grey sandrock, hard. 138-140 Clay rock. 140-147 Gypsum; saline.
147-153 Clay rock.
153-172 Gypsum and clay slate.
172-175 Gypsum. 175-178 Clay rock. 178-179 Gypsum. 179-180 Hard sandrock; fresh water.
180-191 Clay rock.
191-198 Hard sandrock; dark color.
198-216 Soft sandrock, colorless.

216-248 Soft sandrock; blue color.

248-265 Loose coarse-grained sandrock of reddish color. Spring of fresh water.

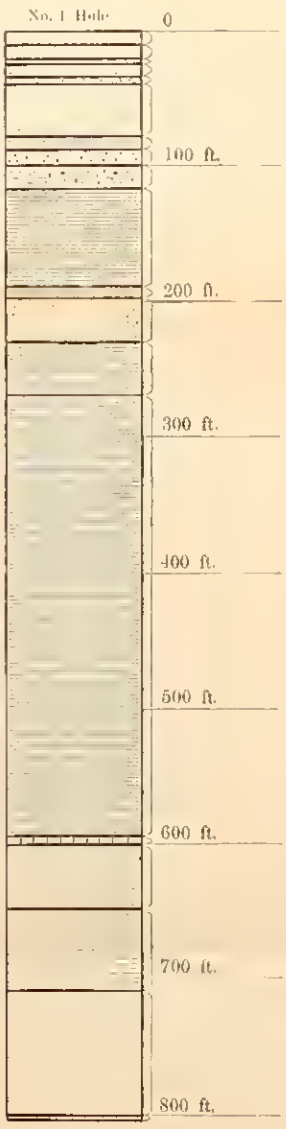
IMLAY CITY.

Plate XXII.

Lapeer Co., Alt. 830 ft.
Walker and Co. Depth 1020 ft.
C. E. Wright. Driller's notes and samples.

Local Names. Correlation by Lane.	Equivalent Depths in Adjacent Wells.	Parallel Names in Ohio by Wright.	Geological Column.	Total Depths.	Driller's Record.
				0	
			LOGAN SERIES		1- 11 Red sand.
					11 S.
					11- 71 Quicksand (mostly.)
					71- 75 Hard pan
					75 S.
				100 ft.	75- 91 Gravel.
					91- 410 S. Blue argillaceous shale; quite soft and somewhat calcareous.
					410- 490 Blue shale. (No sample.)
Marshall ?	cf. Bay City 830-900			200 ft.	490 Flow of fresh water
					490- 498 Red shale. (No sample.)
					498- 580 S. Bluish grey argillaceous shale; contains a very little grit
					580 S.
				300 ft.	
					595- 630 S. Light grey argillaceous shale, very sandy. Under microscope about equal parts of somewhat rounded grains of sand a of clay; sand 1-500 in. in diameter.
					S. (between 630 ft. and 650 ft.)
			CUYAHOGA SHALE	400 ft.	400 S. Light bluish grey argillaceous shale, almost gritless
					450 S. Very sandy argillaceous shale, light grey, (grains of sand partly rounded and 1-600 in. in diameter.)
				500 ft.	
					520 S. Argillaceous shale, light bluish grey, almost gritless A few partly rounded grains of sand 1-1000 in. in diameter.)
				600 ft.	595- 602 Limestone.
Coldwater	cf. Bay City 1220-1500				602 Argillaceous shale, light grey; few very minute shale grains
					610 Argillaceous shale, light grey.
					630 S. Argillaceous shale, light grey.
					650 S. Argillaceous shale, bluish grey, gritless, somewhat salty.
					670 S. Argillaceous shale, bluish grey.
				700 ft.	
					710 S. Argillaceous shale, greyish drab. 708 S. Weak brine.
	cf. Bay City 1898				720 S.
					730 S. Argillaceous shale, dark grey.
					740 S.
					755 Argillaceous shale, very dark drab, gritless.
					770 S. Argillaceous shale, grey.
					782 S. Argillaceous shale, dark blue.
					790 S. Argillaceous shale, dark blue, gritless.
				800 ft.	800 S. Sandstone.
					805 S. Argillaceous shale, light blue, somewhat sandy
					814 S. Argillaceous shale, light blue, gritless.
					825 S.
					835 S. Argillaceous shale, light blue.
			BEREA SHALE		861 S. Argillaceous shale, light blue.
					876 S. Argillaceous shale, dark bluish drab, somewhat shaly, hard.
				900 ft.	857 S.
					900 S. Argillaceous shale, light bluish, soft.
					915 S. Argillaceous shale, light bluish, gritless, soft.
					925 S. Argillaceous shale, dark blue, gritless, soft.
					945 S.
					960 S. Argillaceous shale, light blue, gritless, soft.
					970 S.
					975 S. Argillaceous shale, gritless, soft.
				1000 ft.	985 S. Argillaceous shale, gritless, soft, light blue.
					1010 S. Argillaceous shale, light blue, gritless, soft.
					1015 S. Argillaceous shale, dark bluish drab, slaty and rather hard and gritless.
					1020 S. Reddish shale.
Richmondville ?	Jackson 1344				

Driller's Record
No. 1 Hole

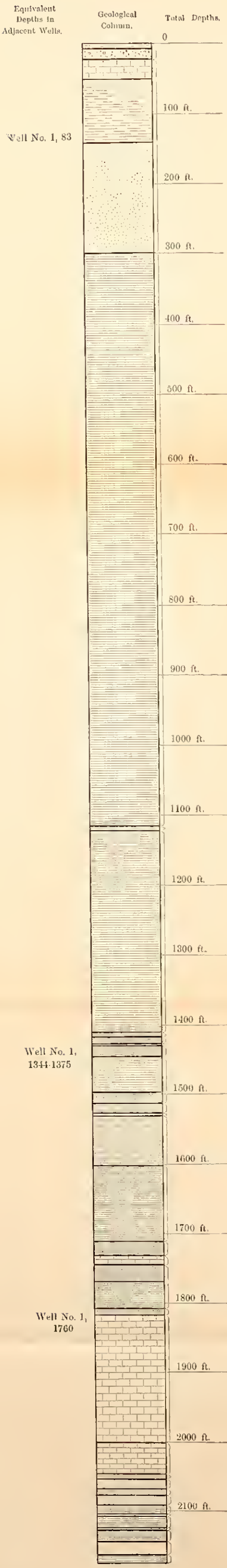


Red sand.
Quicksand.
Fine gravel.
Quicksand.
Gravel.
Quicksand.
White clay.
Gravel.
Hard pan and boulders.
Blue shale.
< Flow of fresh water.
Red shale.
Sandstone, yellow and somewhat salty
Blue shale.
Black shale.
Limestone.
595- 648 Sort of sandy shale, with some brine.
648- 710 Shale, with salt water.
808- 802 Sandrock.

ABBREVIATIONS.

S. is placed after points from which samples are taken.

Woodworth [illegible]rth side of town. [illegible] ft. Cost $7000.
Driller's ? (Fred. Saeger) record. March 4th, 1883.



Depth 2100 ft.
Francis and Milwaukee Sts.; begun April 6th, 1863. Driller's records, probably, from the Jackson Eagle.

Geological Column.

Total Depths.

0 Surface.

1 - 5 Drift.

5 - 65 Sandstone.

65 - 88 Fire clay. Pronounced first class by gas retort men.

100 ft.

200 ft. 88 - 291 Sandstone.

300 ft.

291-388 Limestone.

400 ft.

500 ft.

388-728 Slate.

600 ft.

653 Saline from here on increasingly.

700 ft.

800 ft.

900 ft.

1000 ft.

1010 Salt water, 20 per cent salt.

1100 ft.

1200 ft.

1300 ft.

1400 ft. 1395 Oil in traces.

1443 Argillaceous slate.

1500 ft.

1600 ft.

1700 ft.

1800 ft. 1860 Reached on February 12th, 1864.

1900 ft.

2000 ft. 2000 Reached on June 4th, 1864.

2100 ft.

Kalamazoo Co. Alt. 777 ft.
Kalamazoo Natural Gas Co. Depth 2250 ft.
P. B. Beardsley; samples examined by C. E. Wright, revised and plotted by Lane. Began drilling July 5th, 1887; July 30th struck brine. All of the samples have been kept for years and seem to have been put up in salt water.

Local Names.	Equivalent Depths in Adjacent Wells.	Total Depths.	Sample Record (in part only).
		0	
		100 ft.	1- 130 Surface (approximately. P. B. Beardsley.) No S.
		200 ft.	
			130- 300 Clay and shale (soft); drab color. No S.
		300 ft.	
			300- 320 Black sandstone (hard). No. S.
		400 ft.	
			320- 620 Dark blue shales (soft). No. S.
Coldwater Shales		500 ft.	
		600 ft.	
		700 ft.	
	Berea (?)		620- 820 Light blue soft shale; at 710, 20 ft. red clay. No S.
		800 ft.	
		900 ft.	
	Berea Shale (?)		820-1070 Dark drab soft shale; between 900 and 1000 about 20 ft. red clay. No S.
		1000 ft.	
St. Clair Shale		1100 ft.	
	Ohio Black Shale		1070-1200 Black shale, soft and somewhat sandy. No S.
	S. B.* 305	1200 ft.	
Traverse			1200-1260 Limestone, blue and hard. No S.
	S. B. 365		1260-1270 Blue shale and shale, soft. No S.
	S. B. 381 Brine	1300 ft.	1270-1510 Light grey sandstone, hard, No S. Strong brine. (Probably cherty limestone.)
	Dowagiac 874		
Dundee		1400 ft.	1265 / 1370 / 1400 S. / 1425 S. / 1429 S. Limestone, briskly effervescing, light buff.
			1440 S. Limestone, briskly effervescing, light drab. 1445 S. Limestone, briskly effervescing. } Very sally.
			1450 S. / 1455 S. / 1460 S. Limestone, briskly effervescing, light buff.
	S. B. †D 510 11. 980 / 555 1000		1480 S. Salt and oil. S. Gypsiferous dolomite; effervesces slowly; large residue of anhydrite and one small garnet.
		1500 ft.	1495 S. S. Salt; dolomite; effervesces slowly; large residue of anhydrite.
			1500 S. Salt, dolomite; effervesces slowly; quite ferruginous; much anhydrite.
			1510 S. Dolomite, effervescing slowly, with a small anhydrite residue; light buff.
			1515 S. Dolomite, effervescing moderately, with a small quartz residue; light buff.
			1520 S. Dolomite, effervescing moderately, with small anhydrite residue; light buff.
			1525 S. 1535 S. / 1540 S. Dolomitic limestone, fairly brisk effervescence; quite ferruginous.
			1545 S. Dolomite; slow effervescence.
			1560-1580 Limestone. 1565 Dolomite; slow effervescence; quite ferruginous, with anhydrite.
			1570 S. 1575 S. 1580 S.
		1600 ft.	1585 S. 1590 S. 1595 S.
			1600 S. Salty. S. 1605 S. Very salty S.
			1610 S. / 1620 S. / 1630 S. Brine. S. All essentially the same, effervescing slowly with a copious residue, sometimes, as for 1650, over 50 per cent of anhydrite, with a little quartz (often in sharp dihexahedra), and a red clay, also salt.
			1635 S.
			1640 S. Salty S. largely anhydritic. 1645 S. Gypsiferous dolomite, light buff.
			1650 S. Large residue quartz crystals. 1655 S.
			1670 S. 1675 S.
			1680 S. 1685 S.
			1690 S.
Monroe or Lower Helderberg		1700 ft.	1700 S.
			1720 S. Gypsiferous dolomite, effervescing slowly, with a large residue, light buff, rusty. } Very sally.
			1730 S. White calcareous dolomite, effervescing moderately, with but little residue; some rounded grains of quartz.
	S. B. 900		1740 S. White calcareous dolomite, effervescing moderately; but little residue.
		1800 ft.	1800 Limestone. S. White calcareous dolomite.
	S. B. 950 D 1240 / 1290 / 1310		1850 ? Limestone. S. White calcareous dolomite.
			1875 Limestone. S. Hell sandy shale, slightly calcareous.
		1900 ft.	1940 Sandstone S. Fine-grained white sandstone, (one green grain), mainly rounded.
			1950 Sandstone S. fine-grained white sandstone; generally round sand grains; rarely crystalline.
			1970 S. Reddish ferruginous, sandstone, with grains round or fractured and rarely crystalline.
		2000 ft.	2000 S. Dark shale, with some quartz, much argillaceous matter, carbonates and perhaps also anhydrite.
			2010 S. Like No. 2000 in color, but with less quartz more argillaceous and calcareous matter; effervescence tolerably brisk; chocolate colored.
Niagara		2100 ft.	2080 S. Argillaceous limestone, briskly effervescing; residue as at 2010, grey.
			2120 S. Dark grey dolomite, effervescing moderately.
	S. B. 1000	2200 ft.	2190 S. Light buff dolomite, effervescing slowly; small clay and quartz residue.
			2200 S. Buff dolomite, effervescing slowly. The powder in splinters as if from a hard massive rock.
	S. B. 1100		2220 S. Impure dolomite, as at 2200, with a little quartz and black specks of iron ore and carbon.
	S. B. 1150		2230 S. Iron ore or ferruginous dolomite, with very little quartz, more argillaceous matter.
Clinton or Medina			2250 S. Brown sandstone, with a little calcite; rounded quartz and angular felspar, including microcline!

ABBREVIATIONS.

*S. B. refers to the well at South Bend, Indiana.
†D=Dowagiac.

LUDINGTON, No. 1.

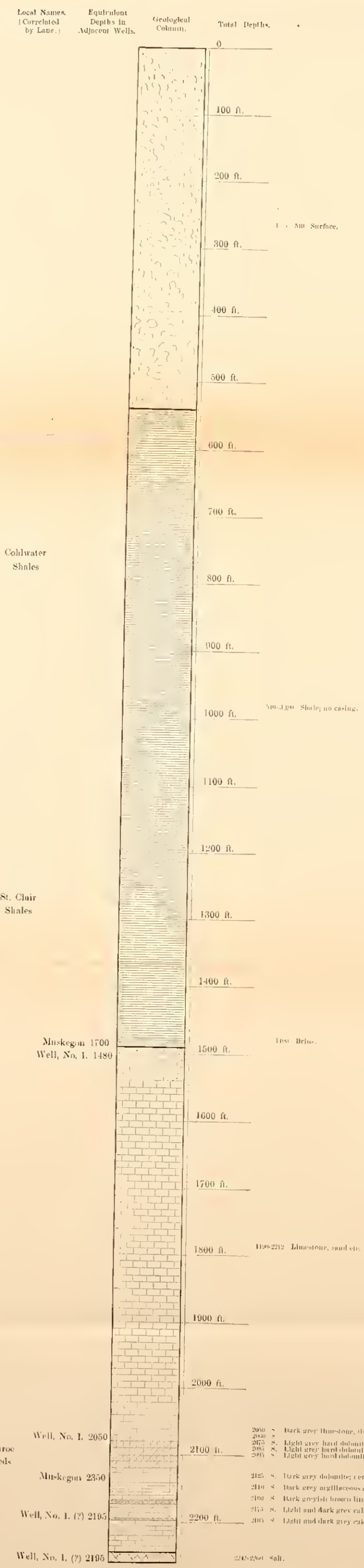
Mason Co. Alt. 590 ft. (10 ft. lower than Butlers and Peters's well and a mile further north.)
Pere Marquette Lumber Co.; H. E. Freeman in charge. Depth 2220 ft.
N. B. Pierre; Mason Co. Record; begun June 20, 1883, finished May 9th, 1885.

Local Names.	Equivalent Depths in Adjacent Wells.	Parallel Names in Ohio.	Geological Column.	Total Depths.			
				0			
					1- 30		Sand.
					30- 35		Marl, shells and blue sticks.
					35- 56		Sand.
					56- 60		Soft clay.
					60- 80		Hard clay.
					80- 90		Hard pan.
				100 ft.	90- 108		Coarse sand and small stones.
					108- 117		Sand and gravel.
					117- 150		Sand.
					150- 183		Sand and gravel.
				200 ft.	183- 200		Sand with clay.
					200- 205		Sand.
					205- 209		Clay.
					209- 214		Clay and gravel.
					214- 241		Clay and sand.
							Surface divided into:
					241- 273		Hard pan.
					273- 284		Clay.
					284- 292		Clay and gravel.
				300 ft.	292- 307		Clay.
					307- 360		Clay and gravel.
					360- 397		Clay.
				400 ft.	397- 412		Clay and sand.
					412- 461		Hard clay.
					461- 476		Hard pan and gravel.
					476- 492		Gravel.
				500 ft.	492- 498		Gravel and sand.
					498- 518		Sand.
					518- 528		Gravel and clay shale.
					528- 573		Blue shale.
					573- 578		Limestone.
					578- 586		Red shale and marl.
				600 ft.	586- 594		Shale.
					594- 699		Limestone.
				700 ft.			
				800 ft.			
				900 ft.	699-1200		Blue shale.
				1000 ft.			
				1100 ft.			
				1200 ft.			In Lyon's No. 2 well a showing of oil at 1165.
St. Clair Shale		OHIO SHALES.	HURON.	1300 ft.	1200-1365	S.	Black slate or hard shale, with pyrite.
				1400 ft.	1365-1435		Blue shale and limestone.
					1435-1480		Black sandy limestone, with strata of gypsum. The limestone is quite crystalline at a depth of say 1460. There are many specks of pyrites.
							Brine 50°.
				1500 ft.	1480-1540		Limestone.
					1540-1560		Limestone and gypsum.
			HAMILTON.	1600 ft.			
					1560-1800		Limestone, hard with grit above, and softer with less grit below.
				1700 ft.			
Muskegon 2000				1800 ft.			Brine 50° - 56°.
			MARCELLUS.		1800-1858		Blue shale
					1858-1862		Salt: either salt or soft salt rock. 100° brine.
					1862	S.	Slow effervescence with some sand grains.
			CORNIFEROUS	1900 ft.	1862-1962		Limestone, very sticky. 70° - 80° brine.
					1920-2005	S.	Bluish argillaceous, moderately effervescent with a large residue.
					1962-2002		Very hard limestone. 20° brine.
				2000 ft.			
			HELDERBERG.		2005-2050	S.	Dolomitic limestone, with a residue of quartz-sand and anhydrite; brisk effervescence.
					2050	S.	
					2062-2110		Dolomite, with soft streaks, 6 in. to 18 in. thick, 56° - 58° brine.
				2100 ft.	2100	S.	Mainly rounded sand, effervescing generally slowly.
							62° - 64° brine.
					2150	S.	Largely rounded sand. Effervescence slow.
					2125-2220	S.	Rusty white sand.
					2140-2195		Hard grey limestone, contains gypsum and is salt in streaks.
				2200 ft.			
			SALINA.		2195-2213		Rock salt. 100° brine.
					2213-2220		Limestone, containing two feet of rock salt.

ABBREVIATIONS.

S. is placed after points from which samples are taken.

Mason Co., Alt. 600 ft. Rently 1 mile south of Ludington in Buttersville.
(2.) Butters and Peters. Depth 2260 ft.
C. E. Wright.



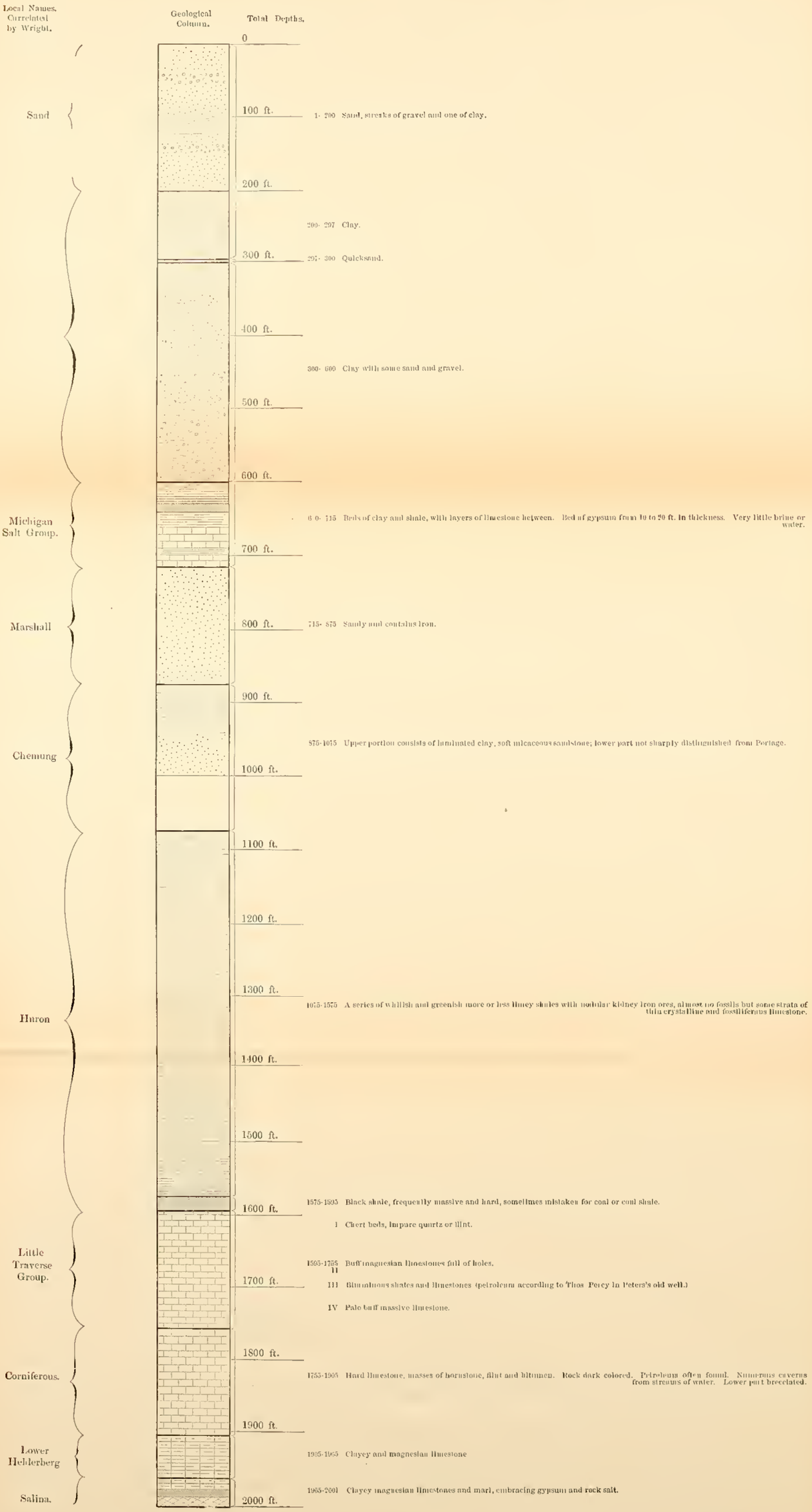
ABBREVIATION.

S. is placed after points from which samples are taken.

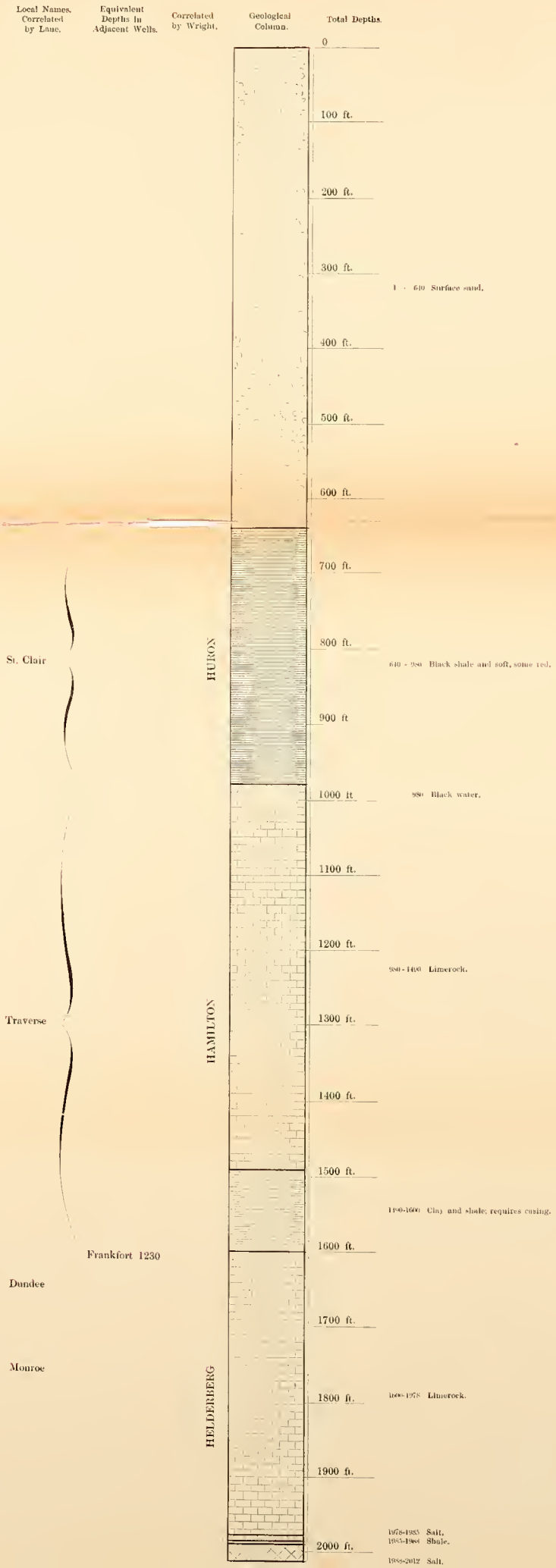
Mason Co., Alt. 590 ft. ± (?).

(3) Peters's old well? If so, in sinking this well there was much intermittent gas as well as petroleum at about 1656 ft., blowing out sand-pump and 450 ft. of rods.

C. E. Wright. Thos. Percy? (Winchell?) This section, which is taken from Wright's notes, is perhaps merely ideal.



Smid's well. Depth 2012 ft.
Thos. Percy.



Caufield and Wheeler (E. D. Wheeler). Depth 1947 ft.
C. E. Wright, E. D. Wheeler; samples in the office of the Survey, which appear however to have got mixed, worked up by Lane.
Analysis of Brine by Albert H. Prescott. Sp. Wt. at 60° F. 1.20054

Ca O SO_3	.4395
(Ca, Mg) Cl_2	.3449
Total solids	26.20
H O	73.80

(Lane)

Names by E. D. Wheeler, except those preceded by S, i. e. represented by samples.

0

0- 93 Sand, with streaks of gravel.

100 ft.

93- 95 Reddish grey clay.

95- 202 Sand.

200 ft.

202- 296 Grey clay

300 ft.

296- 298 Dark reddish clay.
298- 301 Quicksand.

301- 355 All shades of clay; some sand.

355- 358 Gravel.

358- 394 Clay, sand, gravel.

400 ft.

394- 575 Reddish clay, gravel and some sand.

500 ft.

Peters' Well 614

575- 580 Dark clay and gravel.
580- 595 Dark shaly stuff
595- 602 Light shaly stuff.

600 ft.

602- 715 Shale and gravel. S. Contains pebbles of white limestone, argillaceous marl; large residue of clay.

700 ft.

Richmondville or Berea ?

715- 875 Sandrock, with occasional streaks of shale and lime

800 ft.

900 ft.

St. Clair or Ohio Shale

Peters' Well 619—960

875-1075 Shale and streaks of hard lime. S. 965 Light grey limestone and some black shale; medium residue of glassy grains of quartz and black slate.

1000 ft.

1020 S. Greyish calcareous sandstone; large residue of small rounded grains of glassy silica.

1040 S. Light grey limestone, medium residue of milky quartz, glassy quartz and black slate.

1100 ft.

1100 S. Bluish grey argillaceous marl; large residue of clay.

1145 S. Light grey and dark brown limestone, medium residue of glassy quartz and black slate.

1200 ft.

1075-1455 Blue shale.

1300 ft.

Traverse

1290 S. Hard grey and black limestone, with conchoidal fracture; also black and light grey slate.
1310 S. Bluish? argillaceous shale and light grey limestone; also black shale.
1325 S. Limestone as at 1290, and a little blue shale.

1370 S. Light grey marl; very small siliceous residue.

1400 ft.

Peters' Well 1490

1410 S. Siliceous limestone and marl; residue of glassy quartz and grey and dark grey lumps.
1420 S. Calcareous clay; large residue of clay.
1432 S. Bluish grey calcareous clay; residue of clay 90 per cent.

1455 S. Bluish grey calcareous clay, residue of clay 90 per cent.

1500 ft.

1510 S. This sample came up in the slops (i. e. on the sinker rods) when the hole was down 1510 ft. and is like previous samples.

1525 S. and 1530 bluish grey argillaceous shale; residue of clay 95 per cent.
1455-1555 Slicky greyish brown shale, cased 60 ft. above bottom when hole was 1520 ft. deep; brine 20 per cent.

Peters' Well 1600
Frankfort 1230

1555-1575 Shaly lime.

1575-1604 Lime rock.

1600 ft.

Dundee

1620 S. Reddish limestone, with numerous yellow specks of ochre; small residue of clay and silica.

1604-1655 Shale and lime.

1655-1695 Lime streaks, dark and light.
1675 S Yellow grey siliceous limestone; appears quite friable; medium residue siliceous and yellow.

1700 ft.

1695-1705 White lime; brine 30 per cent. from here in 1845. S 1700 Greyish white calcareous clay; large residue.
1705-1725 Lime and shale, hard. S 1735 Light grey argillaceous marl; large residue of clay and gypsum.

1725-1740 Shaly and sticky. S. 1740 Dark buff soft limestone, as at 1675; medium residue of clay and gypsum.
1740-1745 Lime cuts free
1745-1752 Limey shale.
1752-1780 Very hard spots and softer and streaks of lime.

1780-1803 Very hard streaks, with streaks of softer.

1800 ft.

Monroe

1803-1855 Porous rock. S 1810 and 1825 Dark grey or drab dolomite; very small residue; saline.

1855-1845 Porous rock S. 1855. Dark drab dolomite; conchoidal fracture; very hard; very small residue.
1845-1848 Clay lime rock, with hard thin streaks. Brine 80°. S. 1845. Light grey soft limestone; small residue of gypsum and silica.
1848-1858 Softer; cuts very fast.
1858-1865 Soft lime rock. S. 1858. Dark drab dolomite, as at 1855.
1865-1875 Hard and soft streaks. Brine 92°.
1875-1900 Massive lime rock. 930. S. 1877 like to 1858, and a yellowish limestone in small grains; very small residue.
1900-1902 Supposed to be salt. 960.

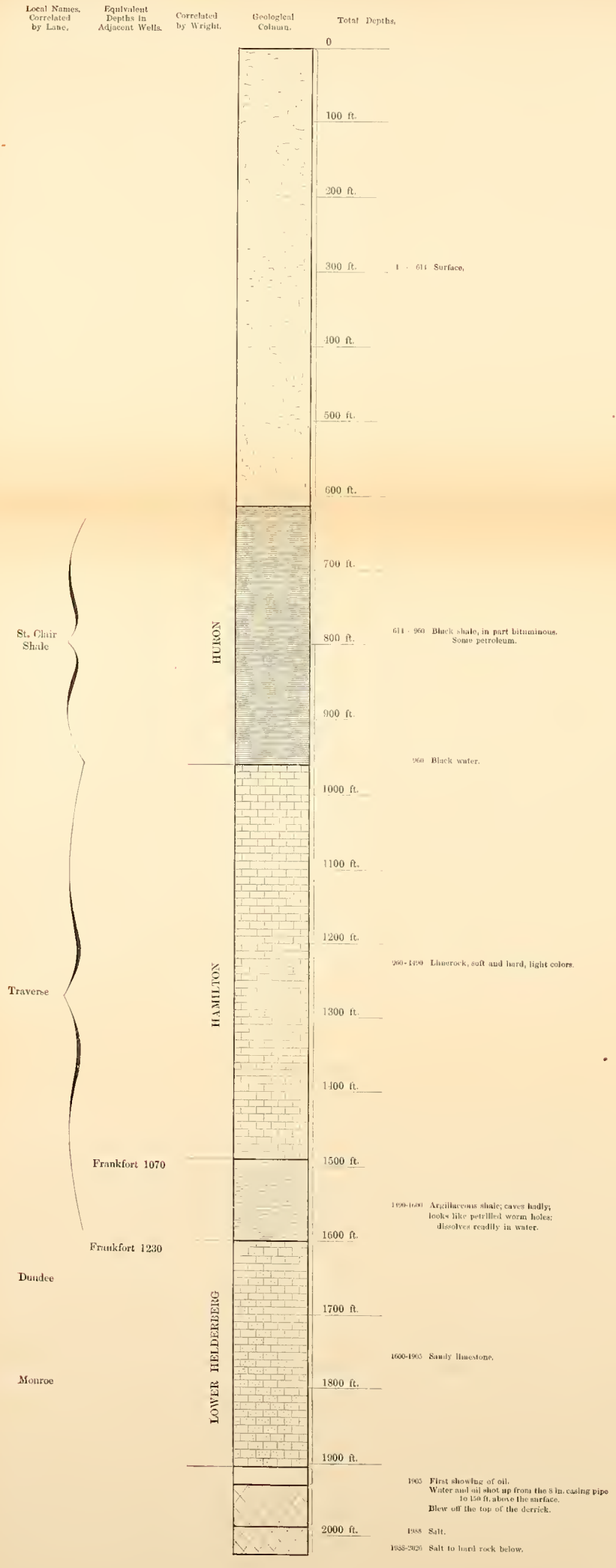
1900 ft.

Peters' Well 1930

1902-1942 Rock salt.

1942-1947 Hard lime rock.

R. G. Peters. **Depth 2026½ ft.**
C. E. Wright. **No Samples. Sunk in 1885. Showed some oil and gas.**



MARINE CITY, No. 1.

St. Clair Co. Alt. about 600 ft.
Lester and Roberts (D. Lester, W. S. Roberts). Depth 1641 ft.
Samples saved by J. R. Burr. Well bored by Matthew Porter. Section by C. E. Wright.

Local Names, Correlated by Lane.	Equivalent Depths in Adjacent Wells.	Correlated by Wright.	Geological Column.	Total Depths.		
				0		
					0- 50	Surface.
				100 ft.		
					50- 200	Clay
				200 ft.		
					200- 210	Hard pan, contains fragments of slate
					210- 220	Hard pan, contains fragments of slate
St. Clair					220- 230	Hard pan
					230- 300	Black bituminous slate, contains FeS_2
		HURON.		300 ft.		
					300- 320	Dark and light drab slate.
					320- 340	Black bituminous slate, contains small pieces of coal.
					340- 350	Dark drab bituminous shale, contains small pieces of coal and FeS_2.
					350- 360	Drab bituminous shale, somewhat calcareous.
				400 ft.	360- 410	Argillaceous dolomitic limestone. { Al_2O_3 14.29. SiO_2 28.67.
					410- 450	Light bluish grey to drab colored limestone.
Traverse					450- 470	Light grey limestone.
		HAMILTON.			470- 490	Light grey limestone, contains a little talc and slate.
				500 ft.	490- 500	Light and dark grey limestone, small siliceous residue.
					500- 550	Soft argillaceous limestone { Al_2O_3 0.70 $S\ O_3$ .21
					550- 560	Dark drab limestone.
		MARCELLUS.		600 ft.	560- 635	Calcareous argillaceous rock, gritless. { Al_2O_3 17.18
	S. B.* 365 385					
				700 ft.	635- 730	Light yellowish grey limestone.
Dundee					730- 770	Light grey limestone, contains oblong concretions or possibly fossils, 5 m m.
Monroe	S. B. 540 555			800 ft.	770- 800	Dolomite, contains yellow specks.
					800- 830	Light brownish drab dolomite; contains in residue a little anhydrite in white specks.
	1st Epoch of Maximum Dessication				830- 855	Light grey dolomite; contains in residue a little anhydrite in white specks.
					855- 880	Dolomite, light drab, contains in residue a little anhydrite in white specks
		CORNIFEROUS.		900 ft.	880- 905	Hard dolomitic limestone, light grey, massive.
					905- 935	Dolomitic limestone, contains a little anhydrite; also a few fragments of slate.
					935- 965	Dolomitic limestone, contains a few fragments of slate.
					965- 980	Dolomitic limestone, light drab, contains in residue a little anhydrite in specks.
				1000 ft.	980- 990	Dolomitic limestone, drab; even texture.
					990-1005	Dolomitic limestone, dark drab.
					1005-1020	Dolomitic limestone, dark drab.
					1020-1050	Dolomitic limestone, dark drab.
					1050-1060	Dolomitic limestone, dark drab.
Sylvania Sandstone		ORISKANY		1100 ft.	1060-1100	Arenaceous limestone, dissolves briskly but leaves a large cherty sandy residue. Not organic.
					1100-1150	Arenaceous limestone.
					1150-1160	Limestone, light drab.
	S. B. 710				1160-1190	Limestone, light grey, contains a little gypsum.
				1200 ft.	1190-1220	Limestone, light grey, contains a little gypsum.
					1220-1225	Dolomitic limestone, dark drab.
	P. L.† 1380				1225-1245	Dolomitic limestone; hard, light grey, yellow specks; large siliceous residue.
					1245-1270	Dolomitic limestone, very dark drab; large siliceous residue.
		HELDERBERG.			1270-1293	Dolomitic limestone, light drab; small siliceous residue.
				1300 ft.	1293-1304	Gypsum, drab and white.
					1304-1330	Calcareous gypsum, dark drab; large residue, possibly argillaceous.
	2nd Epoch.				1330-1365	Calcareous gypsum, dark drab; very large residue, possibly argillaceous. SiO_2 = 12.68.
					1365-1390	Calcareous gypsum, dark drab; large residue, possibly argillaceous; contains anhydrite.
				1400 ft.	1390-1405	Dolomitic limestone, light and dark drab; large residue slate, anhydrite, gypsum and silica and some organic matter
					1405-1425	Dolomitic limestone, light drab; large residue slate, anhydrite, gypsum and silica and some organic matter.
					1425-1445	Dolomitic limestone, light and dark drab; large residue slate, anhydrite, gypsum.
					1445-1465	Dolomitic limestone, light drab; residue slate, anhydrite, silica and some organic matter.
					1465-1485	Dolomitic limestone, light drab; large residue of gypsum.
				1500 ft.	1485-1505	Gypseous limestone, light drab; large residue of gypsum.
					1505-1538	Gypseous limestone, light drab; large residue of gypsum.
					1538-1579	Calcareous clay. Al_2O_3 22.42.
		SALINA.			1579-1599	Anhydrite. SO_3 59.42.
	3rd Epoch.			1600 ft.	1599-1604	Gypsum, white and dark drab.
					1604-1637	Rock salt.
					1637-1641	Gypseous limestone. SO_3 = 14 to
						(Note.—The gypsum is anhydrite. L.)

ABBREVIATIONS.

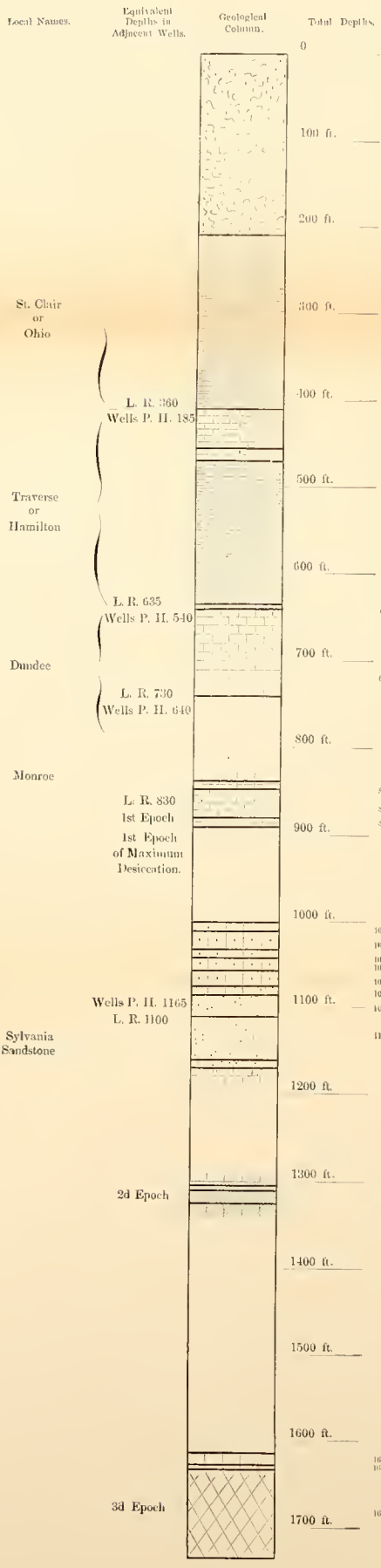
Sil.=Silica=SiO_2
FeS_2 = Iron pyrites.
Al_2O_3 = Alumina.
S. O_3 = Acid Sulphuric.
*** S. B. refers to well at South Bend, Indiana.**
† P. L. Refers to well at Port Lambton.

MARINE CITY, No. 2.

St. Clair Co. Alt. about 600 ft.
Baird Bros. Depth 1735 ft.
R. B. Baird.
C. E. Wright. Begun in 1886. Samples with the State Geological Survey.

Analysis of reddish scales from launder of Salt Works gives

$Si\ O_2$	.48
$Al_2\ O_3$, $Fe_2\ O_3$	.50
K Cl	.89
Na Cl	.39
$Na_2\ SO_4$	1.36
Mg CO	.51
Ca CO	4.04
Ca SO_4	91.06
Loss, etc.	.77
	100.00



1- 210 Surface.

210- 410 Brownish black argillaceous slate. S. bituminous and ferruginous.

410- 445 Hard grey limestone. S. { 410-427 Large argillaceous residue of blue shale; quite a little pyrite. L.

455- 470 Hard grey limestone, with fragments of slate left in the bluish residue.

470- 630 Bluish grey calcareous argillaceous shale; large clay residue. S.
Fossiliferous, brachiopod fragments, crinoid stems, etc.

630- 640 Bluish grey argillaceous limestone; large clay residue. S. (Apparently a mixture of the samples above and below.)
640- 670 Greyish white limestone, very small residue. S. fossiliferous, an occasional cube of pyrite, briskly effervescing; residue brownish flocculent or infinite granules of quartz; no reaction for gypsum; yellowish.

640- 740 Light grey siliceous limestone; residue large, composed of greyish white grains of sand. S. yellowish.

S.?

830- 836 Light grey dolomitic limestone; very small siliceous residue. S. brownish.
836- 846 Grey dolomitic limestone; medium residue of gypsum in white and drab grains. Hard? S.

846- 880 Dark grey limestone, hard; large residue of silica and gypsum. S.

880- 890 Dark chocolate, dolomitic limestone; very small residue, some black carbonaceous matter. S. ferruginous.

1000-1010 Dark grey dolomitic limestone; hard, very small residue. S.
1010-1030 Dark grey dolomitic limestone; medium residue, siliceous. S.
1030-1040 Hard grey dolomitic limestone; medium residue of siliceous matter. S.
1040-1055 Hard grey dolomitic limestone; very small residue of siliceous matter. S. S.?
1055-1075 Hard grey dolomitic limestone; medium siliceous residue.
1075-1085 Hard light grey, and grey *arenaceous*, dolomitic limestone; large residue of light grey sand. S. (chert? L.)
1085-1110 S. Greyish white calcareous sandstone; brisk effervescence for a moment in hot acid, but little dissolves.

1110-1160 Hard greyish calcareous sandstone, with strata of black slate; brisk effervescence for a moment in hot acid, but very little dissolves.

1160 Light grey calcareous sandstone, large residue.
1170 Arenaceous limestone; medium residue.

1304 Calcareous gypsum; black and dark grey.
1310 Calcareous gypsum, more or less shaly, black and grey.
1325 Dark drab gypsum, *dolomitic*; no reaction with hot Cl.?

1615-1629 Rock.
1629-1634 Rock.

1634-1735 Salt

Still in salt.

ABBREVIATIONS.

L. R. refers to Lester and Roberts' well, Marine City.
Wells P. H. refers to the boring or F. L. Wells at Port Huron.
S.=Sample.

MARINE CITY, No. 3.

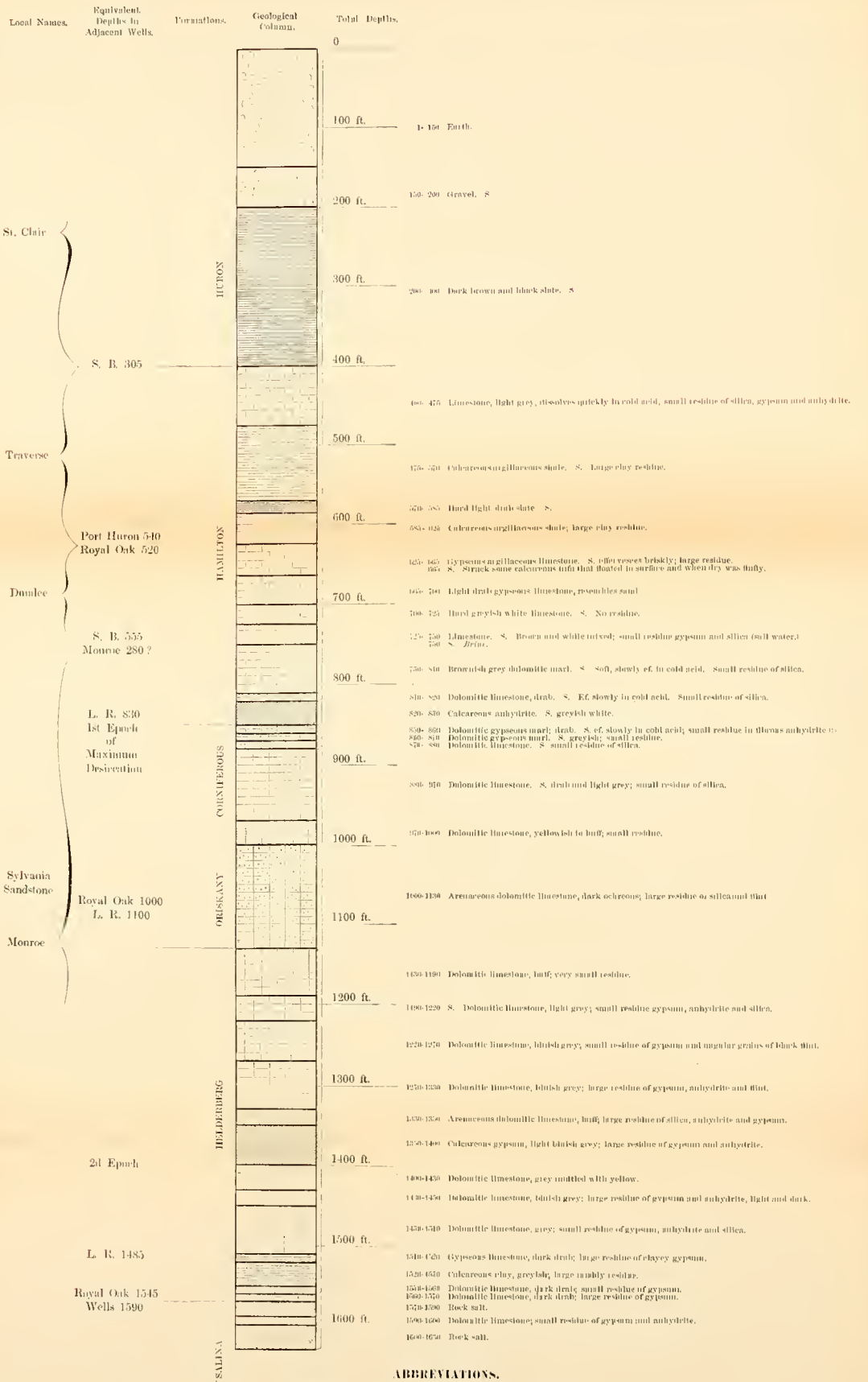
Plate XXXV.

St. Clair Co. Alt. about 600 ft.
Curtis and Lester, Toledo Salt Co. (D. Lester.) Depth 1737 ft.
C. E. Wright. 1884, Aug. 14th to Nov. 17th.

ABBREVIATIONS.

L. R. refers to Lester and Roberts' well, Marine City.
(2) and (3) refer to epochs of desiccation.

St. Clair Co. Alt. about 600 ft.
National Salt Co. Depth 1630 ft. Struck oil and salt at 1577 ft., June 1st, 1886. R. McNeil.
C. F. Wright; samples with State Survey.

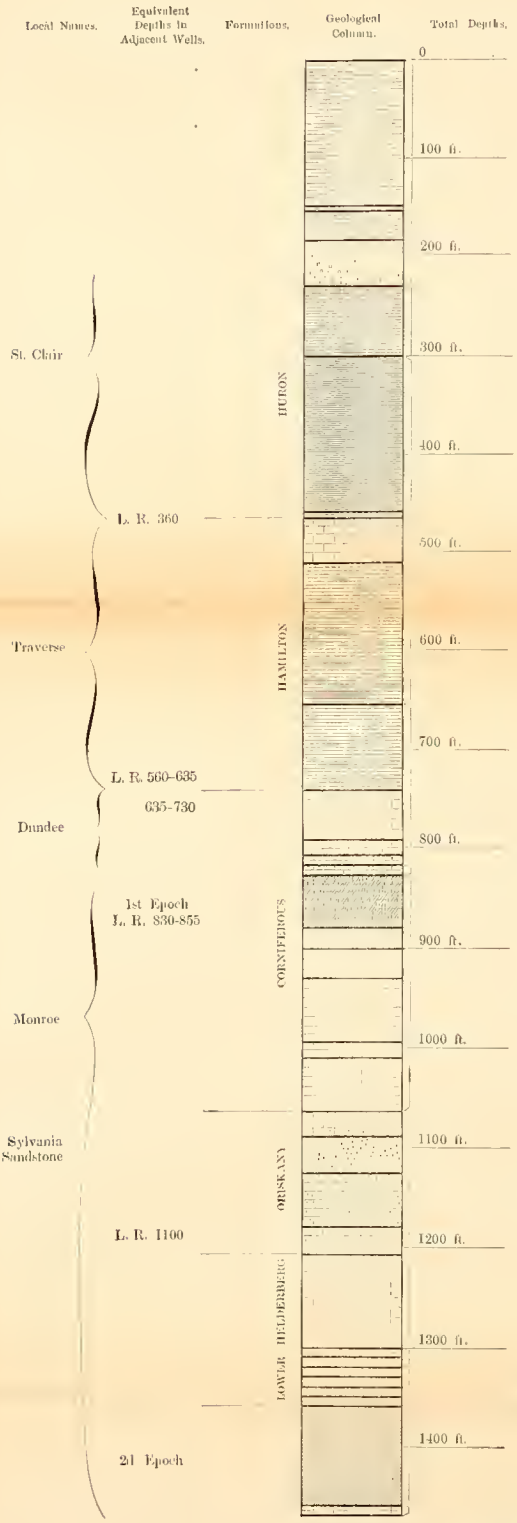


ABBREVIATIONS.

S.=Sample.
L. R. Refers to Lester and Roberts' well, Marine City.
S. B. refers to depths in the well at South Bend, Indiana.
Wells refers to the boring of F. L. Wells at Port Huron.
L.H.=Lower Helderberg.
Ef.=Effervesces.

MARINE CITY, No. 5.

St. Clair Co. (1 mile north of the city. Alt. about 600 ft.
W. B. Morley. Depth 1470 ft.
C. E. Wright; samples; boreal in 1886.



ABBREVIATIONS.

L. R. refers to Lester and Roberts' well, Marine City.

MARINE CITY, No. 6.

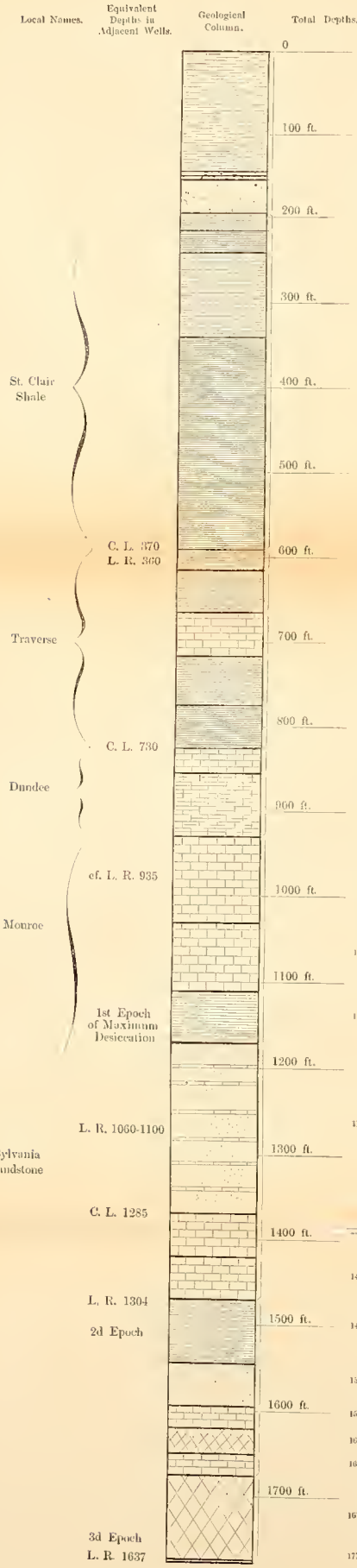
St. Clair Co. (2½ miles north of the city). Alt. about 600 ft.
O. W. Owen. Depth, 1620 ft.
C. E. Wright. Some samples saved by Mat. Porter, 22 Lafayette Ave., Detroit, Mich.

Local Names.	Equivalent Depths in Adjacent Wells.	Total Depths.	
		0	
		90	Clay.
		100	Hard blue argillaceous limestone
		170	Calcareous clay.
		200	Dark drab slate.
		210	Calcareous marl.
Dundee	L. R. 635-730	700 ft.	
		710	Hard grey limestone; small residue of clay and silica.
		750	Hard light grey limestone; very small residue.
		810	Medium hard light grey limestone; very small residue silica and small fragments of slate.
		830	Soft greyish white marly limestone; small residue amorphous gypsum and silica.
		870	Hard light grey limestone; small siliceous residue with black specks.
		880	Hard light grey limestone.
Monroe	L. R. 830 1st Epoch	900 ft.	Buff calcareous marl with yellow spots; small residue of gypsum.
		920	Medium soft greyish white limestone; small residue of clay and SiO_2
		940	
		950	Hard light grey dolomite.
		960	Soft light grey marly limestone; small residue of silica and gypsum.
		1010	Soft grey marly limestone; very small residue.
		1060	Medium hard light grey limestone.
		1080	Dark buff friable limestone; medium residue of silica and black slate.
	Baird 1085	1110 ft.	Dark buff friable arenaceous limestone; large residue milky white, black and glassy quartz
		1140	Greyish white calcareous sandstone; large residue sandstone, 90 per cent.
Sylvania Sandstone		1190	Greyish white calcareous sandstone; large residue sandstone, 90 per cent.
	L. R. 1100 Baird 1160	1200 ft.	
		1270	Greyish drab arenaceous marly limestone; large residue of sandstone and gypsum.
		1300 ft.	Greyish drab arenaceous marly limestone; large residue of sandstone and gypsum.
	Baird 1325	1400	Bluish grey calcareous clay; large clayey residue, some gypsum.
		1400 ft.	
	2d Epoch L. R. 1330	1440	Dark grey gypseous marl; large residue of gypsum and some silica.
		1460	Hard greyish limestone with yellow specks; medium residue of silica and gypsum, salty.
		1500 ft.	Dark grey marly limestone; medium residue of gypsum and silica.
		1620	
		1600 ft.	
	3d Epoch Baird 1634		Salt.

ABBREVIATIONS.

L. R. refers to Lester & Robert's well, Marine City.
Baird refers to Baird's well, Marine City.

St. Clair Co. Alt. about 600 ft.
Marine City well. Depth 1777 ft.
C. E. Wright. In his notes we find this section attributed to Marine City, without further details. The section agrees with others from that place, except that corresponding horizons are somewhat deeper in this well. It is therefore probably west of the city.

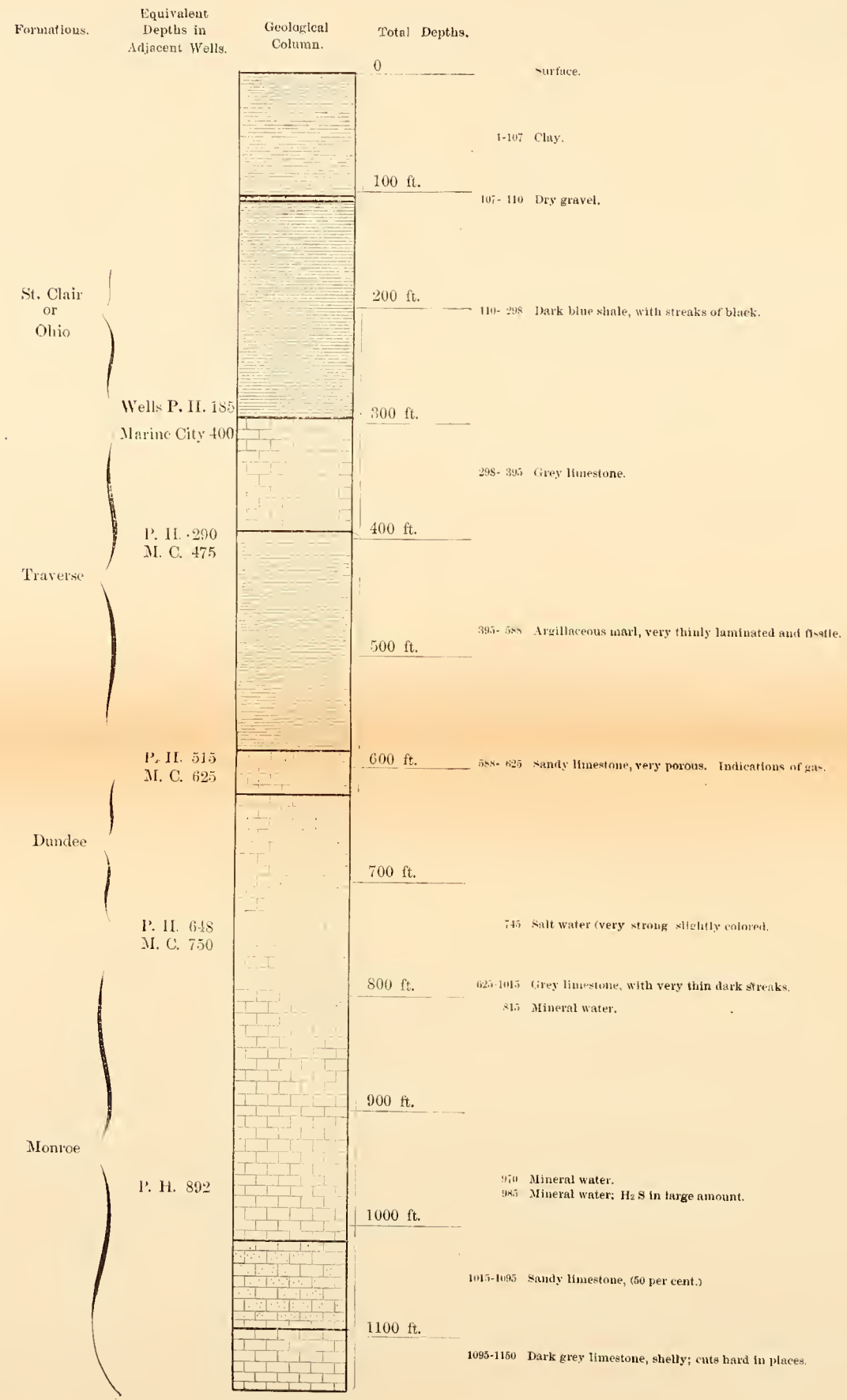


1- 145 Blue clay.
145- 151 Gravel.
151- 155 Boulders.
155- 195 Hard pan, quite black.
195- 215 Light shale, quite hard.
215- 240 Dark shale, quite hard.
240- 340 Light shale, soft.
340- 590 Black shale, quite hard; show of oil and sulphur.
590- 615 White shale, soft.
615- 665 Blue shale, soft.
665- 715 Hard limestone.
715- 775 Sticky blue shale.
775- 825 Black shale.
825- 855 Black limestone.
855- 930 Black rock, looks like oil rock with black water in it; also large show of petroleum oil mixed with gas.
930-1030 Hard grey limerock.
1030-1110 Hard brown limerock.
1110-1170 White shale. [Anhydrite?]
1170-1370 Sandrock, with streaks of limerock, 3 to 5 ft. thick. Water clear; runs over top of casing pipe. Brine stands 90 per cent.
1370-1420 Hard limerock, brown color cleft off here and put in 5 in. casing.)
1420-1470 Hard grey limerock.
1470-1545 Blue shale, somewhat sticky.
1545-1595 Black sand; no water in it.
1595-1620 Hard grey limerock.
1620-1650 Solid salt.
1650-1675 Hard limerock, greyish blue.
1675-1775 Salt.
1775-1777 Hard limerock.

ABBREVIATIONS.

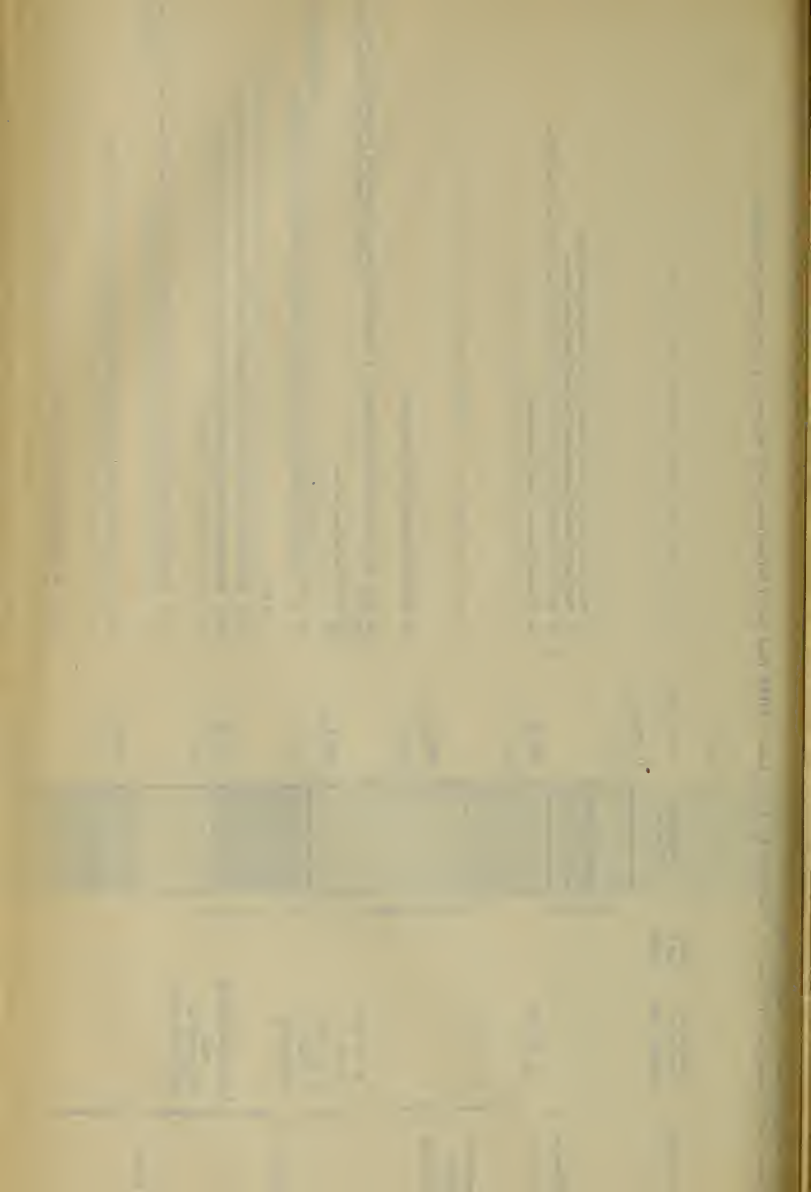
L. R. refers to Lester & Robert's well, Marine City.
C. L. refers to Curtis and Lester's well, Marine City.

St. Clair Co. Alt. about 600 ft.
Binie farm, 4 miles south of Port Huron; begun June 30th, 1887; Section drawn Aug. 6th, 1887.
Church and Co. Depth 1150 ft.

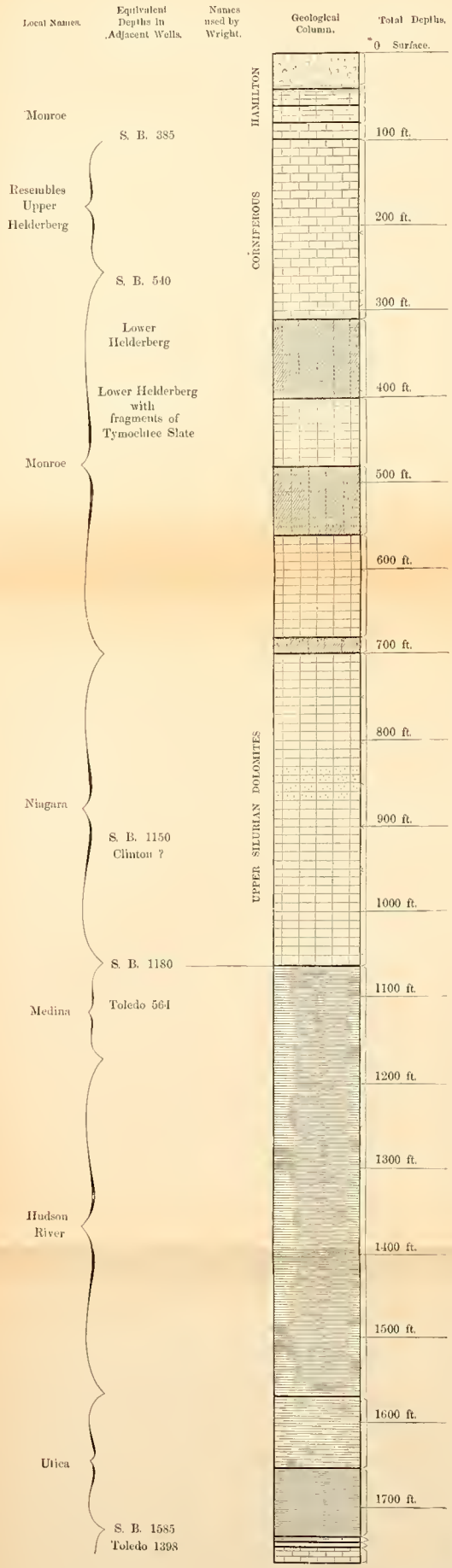


ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells at Port Huron.
M. C. refers to the boring at Marine City.



Monroe Co. Alt. 626 ft.—579 ft.
Monroe well, Monroe Co. Depth 1765 ft.
H. Shaw Noble; samples with Survey, described by A. C. Lane. NOTE that in all formations rusty magnetic grains occur occasionally



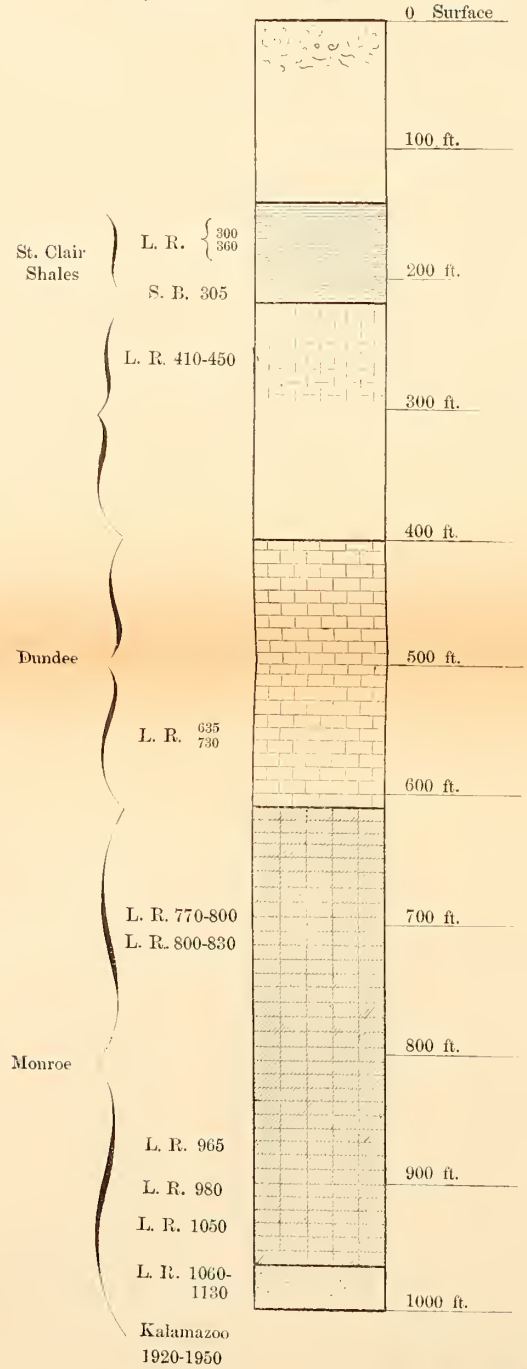
40 Bluish shale, with only a small amount of effervescent calcareous matter.
60 Bluish shaly dolomite, with quite a little slowly effervescing matter.
70-80 Bluish shaly dolomite, with quite a little slowly effervescing matter and a large clay residue.
100 Yellowish limestone, briskly effervescing.
210 Yellowish limestone, briskly effervescing.
260 S. M. Here and at 350, 500 and 650, samples of a white earthly powder of calcite and dolomite, with a trace of gypsum, (probably a chemical precipitate from underground water.)
280-297 Water, 3000 gallons per hour.
340 S. Dolomite; effervesces slowly when in fine powder; contains much anhydrite of a dark buff color.
S. M.
370 S. Buff dolomite; effervesces slowly; in splinters as though from a massive layer, with anhydrite.
390 S. Buff dolomite like the sample above, mixed with greenish dolomitic shale ? with gypsum.
450 S. Buff dolomite like the sample above, effervesing moderately fast, with an occasional fragment of the green shale. little or no sulphate of lime.
500 S. M. S. Light colored calcareous dolomite, effervescing moderately, with much anhydrite.
550 S. Light colored calcareous dolomite, effervescing slowly; in course chips, with much anhydrite.
600 Trace of gas. S. Light colored dolomite, effervesces slowly; an occasional grain of sand; no anhydrite.
650 S. M. S. Light grey dolomite; effervesces slowly; an occasional grain of sand.
700 S. Light grey dolomite; effervesces slowly, reacts for gypsum.
750 S. Light yellowish dolomite; effervesces slowly; quite ferruginous; no gypsum.
800 S. Bluish grey dolomite; effervesces slowly.
850 S. White arenaceous dolomite; effervesces slowly; with grains of quartz, sand and a very little magnetite.
900 S. White arenaceous dolomite; effervesces slowly; with grains of quartz sand; contains a little magnetite; like the formation at 1150 of the South Bend well, Indiana.
950 Salt?
1050 Last limestone before shale. S. grey dolomite, effervescing slowly with a trace of quartz.
1110 S. Greenish and reddish shales, effervescing slightly; mostly clay.
1150 S. Greenish and reddish shales, effervescing slightly; mostly clay.
1250 S. Bluish grey, somewhat ferruginous shales, slightly effervescing.
1400 S. Bluish grey, somewhat ferruginous shales, slightly effervescing. with infinite grounles of quartz.
1570-1655 S. Green and red ferruginous shales, slightly effervescing, with a trace of magnetite.
1655-1735 Next above Trenton, S. black bituminous shale, effervescing slightly, fusing with an aromatic odor and luminescence to a blebby enamel; a little finely divided quartz.
1734-1740 First screw in Trenton. S. Buff colored dolomite; hard, with slow effervescence. At 1742 gas, odorless with white flame;
1745-1750 Third screw in Trenton. S. } Both buff colored limestone. considerable salt water!
1750-1765 4th, 5th and 6th screw in Trenton. S. }

ABBREVIATIONS.

S. is placed after points from which samples are taken.
S. M. From all the points thus marked one mixed sample was obtained.
S. M. S. Beside the mixed sample there is also an individual sample.
S. B. refers to depths in the well at South Bend, Indiana.

MT. CLEMENS, No. 3.

Macomb Co. Alt. 617 ft.: somewhat higher than the other wells, but not 25 ft. above Lake St. Clair.
Owner, Mr. Coursin. Depth 1060 ft.
Mr. Nims, driller; samples furnished by him through T. M. Crocker, Esq., who kindly furnished supplementary information. Sunk in May—July, 1892.



Driller's "log".	Samples.
- to 35	Wet dark grey sand with an oily smell and moderately free effervescence.
- Rock at 123 ft.?	
- 140	Burns with an aromatic odor, in shaly flakes; black; smells oily.
- 210	Like the above, not so bituminous, tastes of ferrous sulphate.
- 218	Mixture of black shale and of a limestone like that at 260 ft.; effervescence not very brisk; traces of gypsum in solution.
- 260	Light buff with traces of shells; very brisk eff.
- 285	The same.
- 300	The same; no gypsum.
- 400	Light yellowish buff.
- 480	
- 560	Light buff; even grained; very brisk eff.; no $CaSO_4$
- 583	Light buff; even grained; very brisk eff., no $CaSO_4$
Gas at 600 ft. and at intervals for the next 200 ft.	
- 610	As at 560.
- 620	As at 560, but slower effervescence.
- 635 - 650	Like 560 in color, but with many large pieces of gypsum, and slow effervescence.
- 675	The same, with a certain amount of gypsum.
- 700	The same, with a certain amount of gypsum.
- 715 - 718 - 720	Brown; slow effervescence, except a few grains; some gypsum.
- 760	Dark buff; slow effervescence; gypsum.
- 785	Dark grey, slow effervescence; gypsum.
- 855	Dark grey; effervescence; gypsum.
- 860	Dark grey; effervescence; gypsum.
- 870	
- 890	Effervesces faster than No. 900; quartz occasional.
- 900	Dark brown; with a trace of gypsum.
- 920	Like No. 720 in color; moderate eff.; occasional quartz; trace of gypsum.
- 940	Brownish buff; quick eff.; a little quartz, chert and clay.
- 965	Like 940, but a shade lighter.
- 985 - 995	Granular white sandstone, very pure; rounded grains averaging 0.3 mm. in size, and smaller angular grains, averaging 0.15 mm. in diameter, like the sand at 1920 ft. and 1950 ft. under Kalamazoo.

ABBREVIATIONS.

L. R. refers to Lester and Robert's well at Marine City.
S. B. refers to depths in the well at South Bend, Indiana.
Eff.=Effervescence.

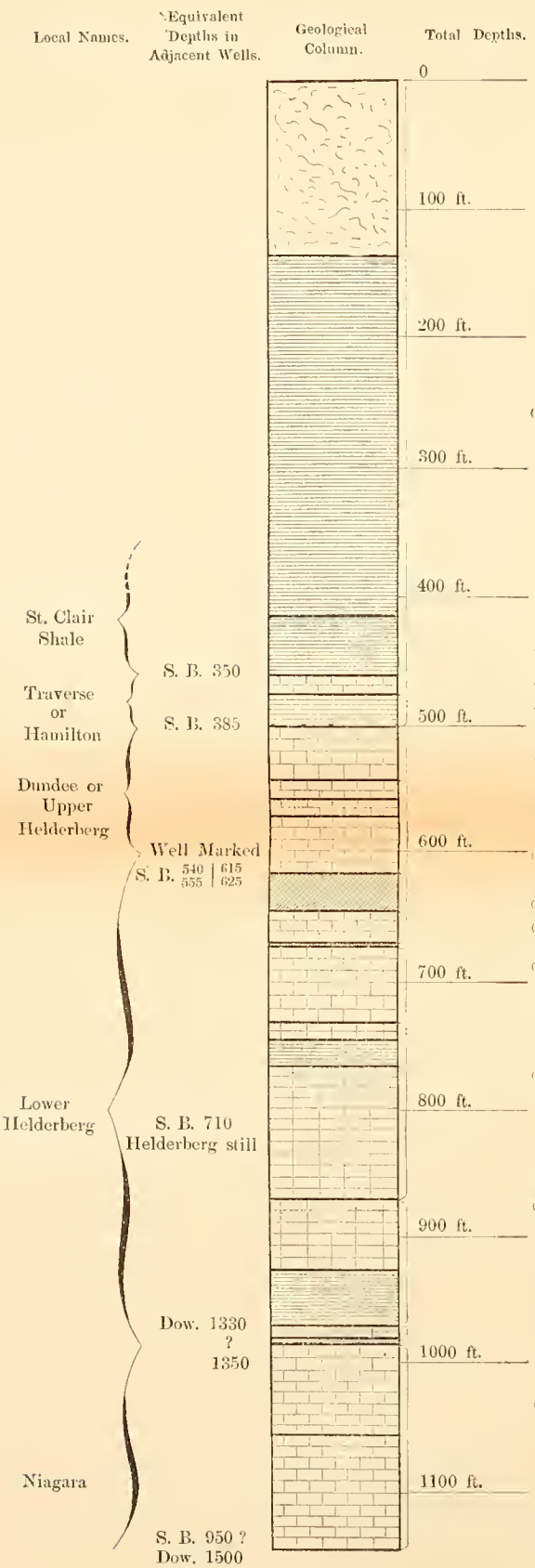
Muskegon Co. Alt. 594 ft.
Mason Lumber Co. Depth 2027 ft.
L. G. Mason; finished 1875.
Near Occidental Hotel.

Local Names.	Equivalent Depths in Adjacent Wells.	Corresponding Names in Ohio.	Geological Column.	Total Depths.	
				0	
					0–60 Sand.
				100 ft.	
					100–200 Clay.
				200 ft.	
					200–225 Hard pan.
					225–300 Sandrock
					Seam of iron pyrites
				300 ft.	Shale
					Sandrock
					Shale.
				400 ft.	
		WAVERLY			475–500 Shales and sandrock alternating.
				500 ft.	
				600 ft.	
	G. R. 400				Hard blue, some of it dark grey and shale.
				700 ft.	Strong flow of mineral water.
Coldwater Shale					
				800 ft.	
				900 ft.	
				1000 ft.	925–1400 Blue shale, with streaks of some soft material.
				1100 ft.	
	G. R. 1200 Kalamazoo 710			1200 ft.	Petroleum and gas. Good lubricating oil, estimated 35 barrels a day.
?					
				1300 ft.	
	G. R. 1500	OHIO SHALES.		1400 ft.	
					1500–1560 Solid blue shale.
St. Clair Shale	Kal. 1070			1500 ft.	
				1600 ft.	
					1650–1700 Solid red shale.
	Ludington 1480 Kal. 1200 Dow. 765 G. R. 1700 —1775			1700 ft.	
				1800 ft.	
		HAMILTON			1800–2000 Limestone, with streaks of shale and soft limerock.
Traverse and Dundee				1900 ft.	
	Ludington 1800			2000 ft.	
					2003–2050 Salt-bearing rock, with streaks of sand, 1 to 1 ft. thick. Cannot say whether salt was struck or not. Brine 1st
	Kalamazoo 1495	ORISKANY			2050–2100 Light colored limerock and shale.
				2100 ft.	
Monroe ?				2200 ft.	2100–2200 Dark colored limerock, (dolomite? probably and so indicated in a section drawn under Wright's direction.)
				2300 ft.	
	Dow. 1310 ?				2350–2400 Gypsum and lime in streaks, 1 to 6 ft. thick.
				2400 ft.	
					2400–2500 Limerock and gypsum, a little less gypsum than in preceding and more lime.
		SALINA		2500 ft.	
					2500–2621 Rapid and variable changes ending in dark limerock, loose and porous
				2600 ft.	limerock.

ABBREVIATIONS.

Dow. refers to well at Dowagiac.
Kal. refers to well at Kalamazoo.
G. R. refers to well at Grand Rapids.

Berrien Co., Alt. 681 ft.
Depth 1140 ft., but by actual measurement 1099 ft.
Chas. L. Davis, C. E. Wright: samples with the Survey.
NOTE.—Names in parentheses are probably the Driller's.



(1- 139 Surface.)

139 S.

(139- 415 Argillaceous shale), dark blue, quite hard and slaty; no effervescence.

415 S.

415- 460 Red shale, dark brownish red bituminous shale; contains considerable iron pyrites.

460 S.

460- 475 Argillaceous limestone, dark drab, soft; brisk ef. in cold HCl.; 10 per cent argillaceous residue.

475 S.

475- 500 Calcareous argillaceous shale, dark drab; contains iron pyrites; brisk effervescence; residue 70 per cent of clay.

500 S. Granular limestone, buff, soft and friable; brisk ef.; 5 per cent residue of angular grains of silica, some opaque.

500- 605 S.

540 S. Sandy limestone, light buff, med. grained; brisk ef.; 40 per cent res. of rounded glassy grains of sand and some that are not glassy.

555 } S. Sandy limestone, light grey, brisk ef.; 20 per cent res. of rounded glassy grains of sand.
560 }

590 S. Limestone, light drab; brisk ef. in cold acid; 5 per cent residue of rounded glassy grains of sand.

(605- 625) (Limestone.)

615 S.

625 S. Calcareous anhydrite, snow-white. Under microscope, composed chiefly of anhydrite, 90 per cent, and say 1 per cent of drab limestone.

(625- 635) S. (Gypsum.

645 S.

(635- 670) S. (Dolomite) drab; 3 per cent of clay and gypsum (anhydrite).

660 S.

680 S.

(670- 710) (Limestone.)

720 S. Limestone mixed with 20 per cent of snow-white gypsum and anhydrite. [The snow-white grains under microscope are composed chiefly of anhydrite; residue contains some clay.]

(Blue shale.)

(710- 735)

730 Dolomitic limestone, drab; very even texture; slow effervescence; 10 per cent residue of anhydrite.

745 S Very siliceous argillaceous shale; no effervescence; light bluish drab color.

765 S.

(735- 850) (Limestone, crinoidal?)

785 S.

810 S. } Dolomitic limestone, light drab; very even texture; slow effervescence; 1 to 2 per cent residue.
825 S. }

850 S.

(850- 940 Slate.)

870 S. Argillaceous dolomitic limestone, light drab; slow ef. in cold acid; 10 per cent residue of clay.

925 S.

930 S. }
935 S. } Calcareous argillaceous slate or shale, black; 80 per cent black argillaceous residue. Partially disintegrates.
950 S. }

970 S. Dolomite, dark drab; slow effervescence; 10 per cent very dark clay residue.

980 S. Calcareous clay shale, dark drab and grey black; 80 per cent of dark drab and black clay residue.

985 S. }
1000 S. } Dolomite, buff to cream color; 1 per cent residue.

1020 Oil.

(940-1090) (Limestone.)

1035 S.

1040 S.

1050 S.

1055 S.

1070 S.

1080 S.

1090 S. Dolomite, creamy white and light grey, very fine grained, lithographic in texture, somewhat ferruginous, decidedly more so than the upper limestone; 5 to 7 per cent of anhydrite and gypsum ?)

1110 S.

1125 S.

1140 S.

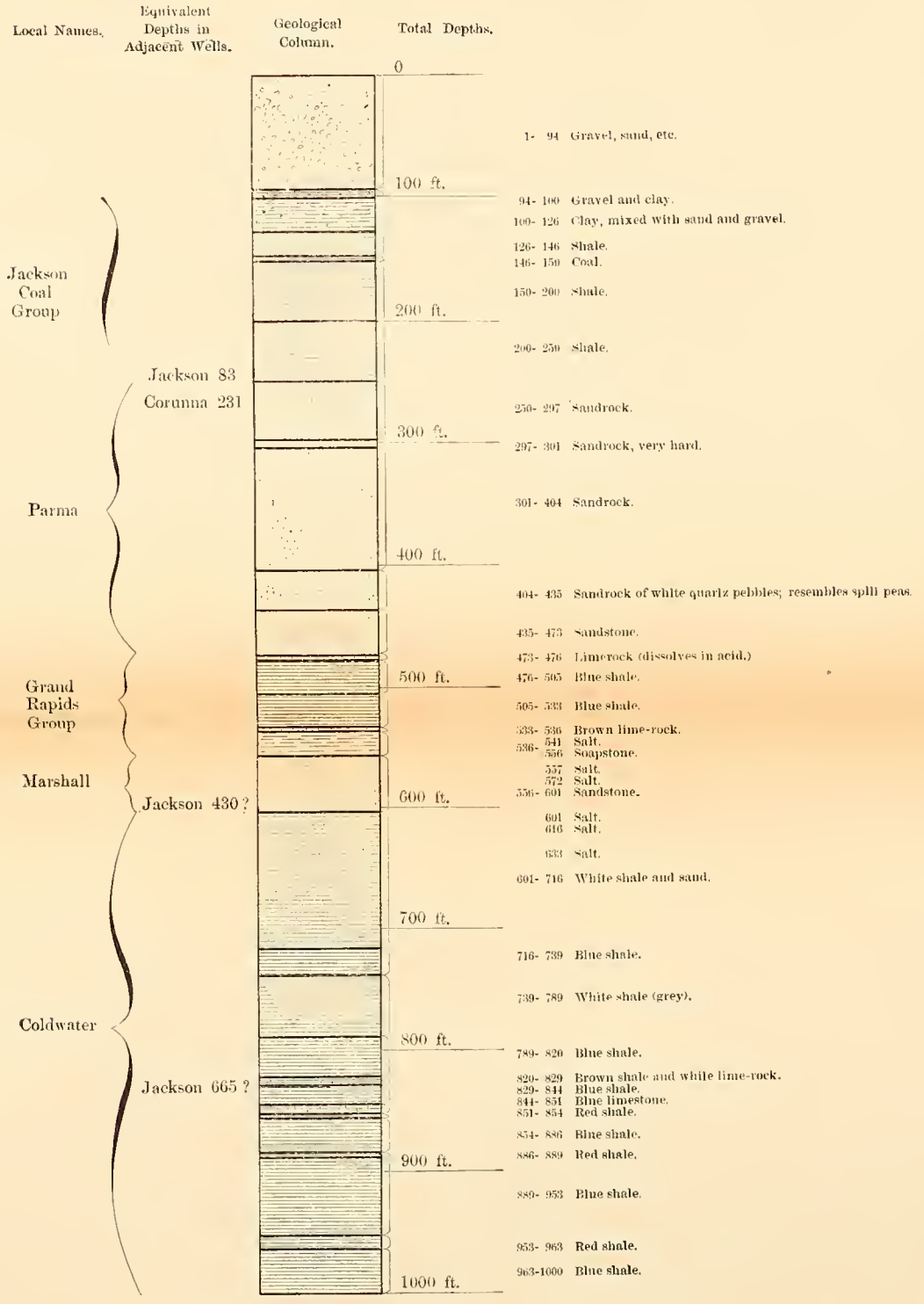
1145 S.

ABBREVIATIONS.

Ef.=Effervescence.
HCl.=Muriatic acid.
Res.=Residue.
S. B. refers to depths in the well at South Bend, Indiana.
Dow. refers to depths in the well at Dowagiac.
S. is placed after points from which samples are taken.

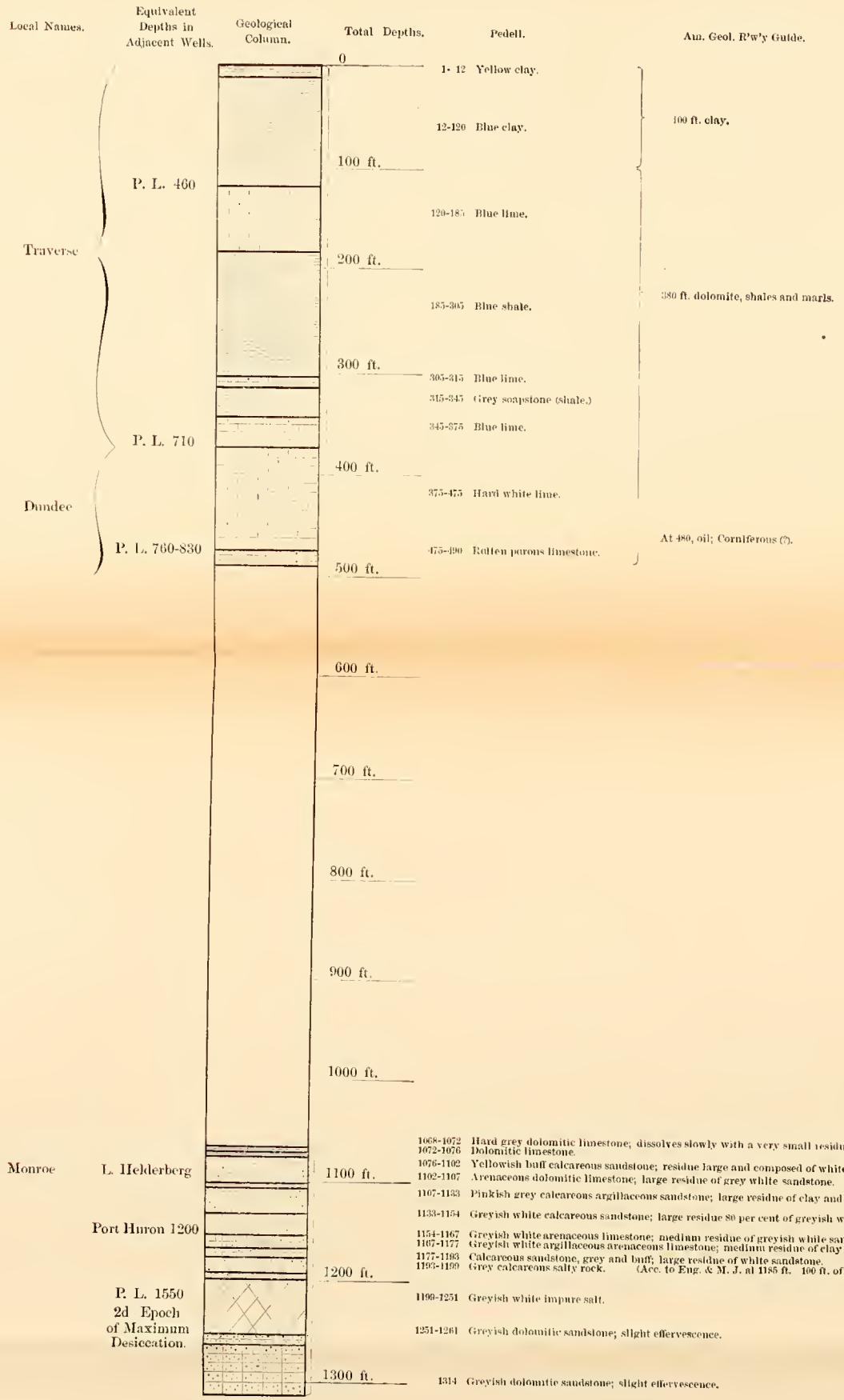
OWOSSO.

Shiawassee Co. Alt. 745 ft. Four miles northwest of the town. Thos. ? 's farm.
G. W. Collyer, 1863. Depth 1000 ft.
C. E. Wright. Compare also Rominger, III, p. 97, well of Mr. Conrler.



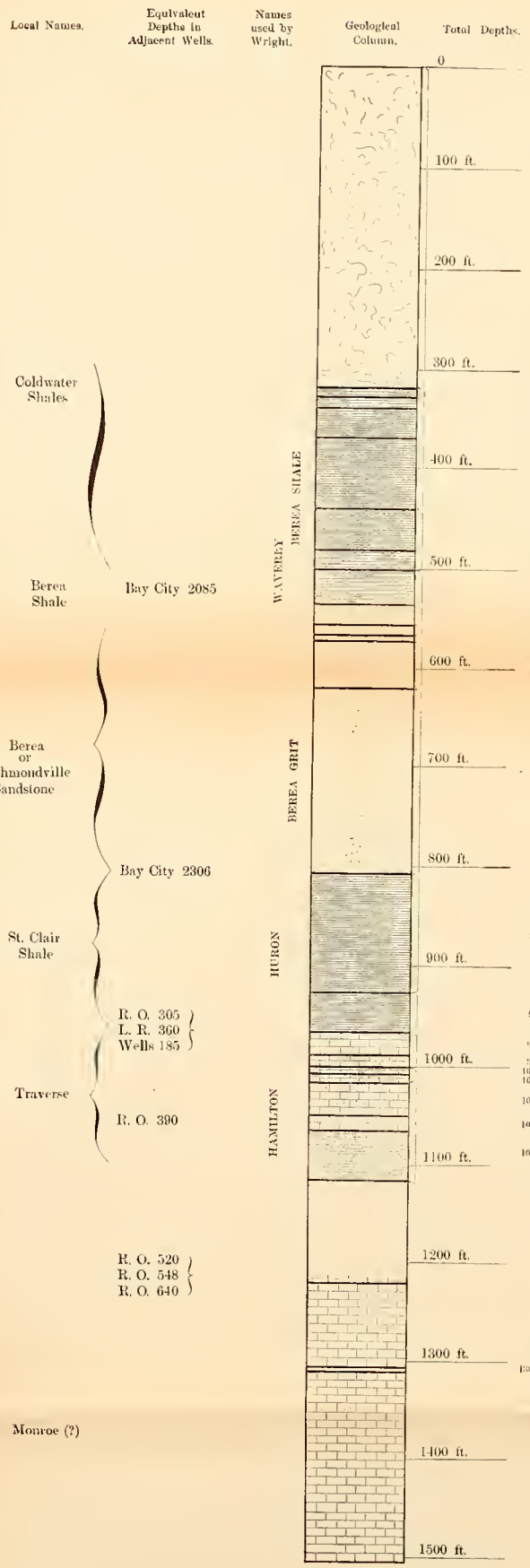
Pontiac Natural Gas and Oil Co. Depth Logs II.

Eighteen miles from Port Huron. Alt. 647 ft. (?)
Wm. Pedell authority for first 490 ft. C. E. Wright; samples with the survey. Depth 1314 ft.
See also Am. Geological R'w'y Guide, and Eng. and M. J., May 1st, 1880, quoted from "Petrolia Topic," which attributes the ownership of the well to J. L. Englehart.



ABBREVIATIONS.
P. L. refers to the well at Port Lambton.

Oakland Co., Alt. 934 ft.
Pontiac Natural Gas and Oil Co. Depth 1505 ft.
G. S. Duncan, Contractor. C. E. Wright; samples with State Survey.



Surface.

320- 330 Blue shale.
330- 340 Blue argillaceous shale.
340- 370 Calcareous argillaceous sandy shale; light blue; very fine grained.
370- 440 Sandy argillaceous shale, light blue.
440- 480 Sandy argillaceous shale.
480- 500 Reddish argillaceous shale
500- 535 Dark brown argillaceous shale.
535- 555 Light drab sandstone; fine grained. Salt water
555- 565 Light drab sandstone; fine grained.
565- 572 Light drab sandstone; fine grained.
572- 620 Grey sandstone.
620- 808 Grey sandstone.
808- 925 Black shale.
925- 965 Black shale.
965- 990 Coarse-grained argillaceous limestone, dark drab.
990-1000 Fine-grained limestone, light drab; 2 per cent insoluble residue.
1000-1007 Limestone, light drab and greyish white; 8 per cent insoluble residue.
1007-1015 Limestone, light grey; 20 per cent insoluble residue.
1015-1050 Sandy limestone, dark drab; 20 per cent insoluble residue
1050-1065 Argillaceous limestone; 10 per cent insoluble clay residue
1065-1115 Light blue calcareous clay; 90 per cent insoluble residue.
1115 Salt water; very strong brine.

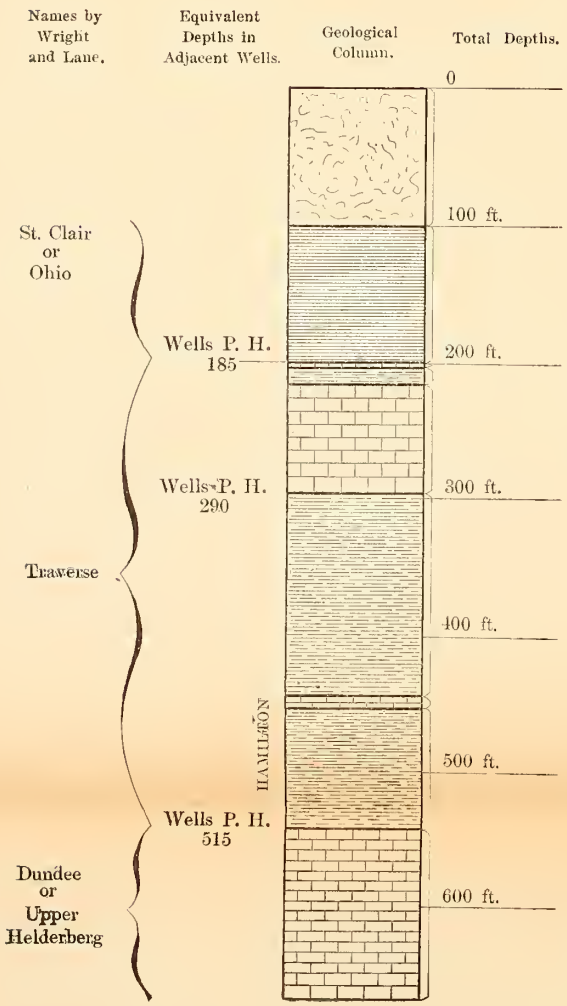
	Driller's record.	Samples.
1220	Mineral water.	
1231		Limestone and shale, dark drab and grey mixed; very brisk ef.; residue 5 per cent of clay.
1240		Limestone, drab; very brisk effervescence; residue, 1 per cent of clay.
1250	Mineral water.	
1261		Limestone, drab; very brisk effervescence; residue, 1 per cent of clay.
1272		Limestone, dark drab; very brisk effervescence; residue, 2 per cent of clay and sand.
1285		Limestone, light grey, fine; brisk effervescence; residue, 2 per cent of sand.
1300		Limestone, grey drab; brisk ef.; residue, 5 per cent of sand, glassy and grey.
1305-1340	Show of gas.	
1340 } 1350 }		Arenaceous limestone; light grey; brisk ef.; residue, 20 per cent grey sand and some glassy grains.
1425	Same rock from 1220 down.	
1497	In gas-rock for 40 ft. (?), but 1160 ft. water in well.	

ABBREVIATIONS.

Ef.=Effervescence.
Res.=Residue.
R. O. refers to the well at Royal Oak.
L. R. refers to the well of Lester and Roberts, Marine City.
Wells refers to the well, at Port Huron, sunk by F. I. Wells.

PORT HURON, No. 1.

500 N., 1000 W., S. 9, T. 6, N., R. 17. E.
C. A. Bailey, No. 1. Depth, 668 ft.
C. E. Wright and A. C. L.; samples with the State Survey.



1-100 Surface.

100-200 Black slate or shale.

200-202 S. Streak of hard argillaceous lime containing FeS.; medium residue clay.
202-217 Soapstone (argillaceous marl.)

217-297 Top limestone.
280 Blow of odorless gas.

297-444 Soapstone. (Argillaceous marl.)

444-453 Limestone, middle; light grey; very small residue of silica.

453-543 Soapstone, lower.
518 S. Top of lower lime; small silliceous residue.
525 S. Light grey hard limestone; scarcely any residue. Oil rock.

543-668 Limestone, lower.

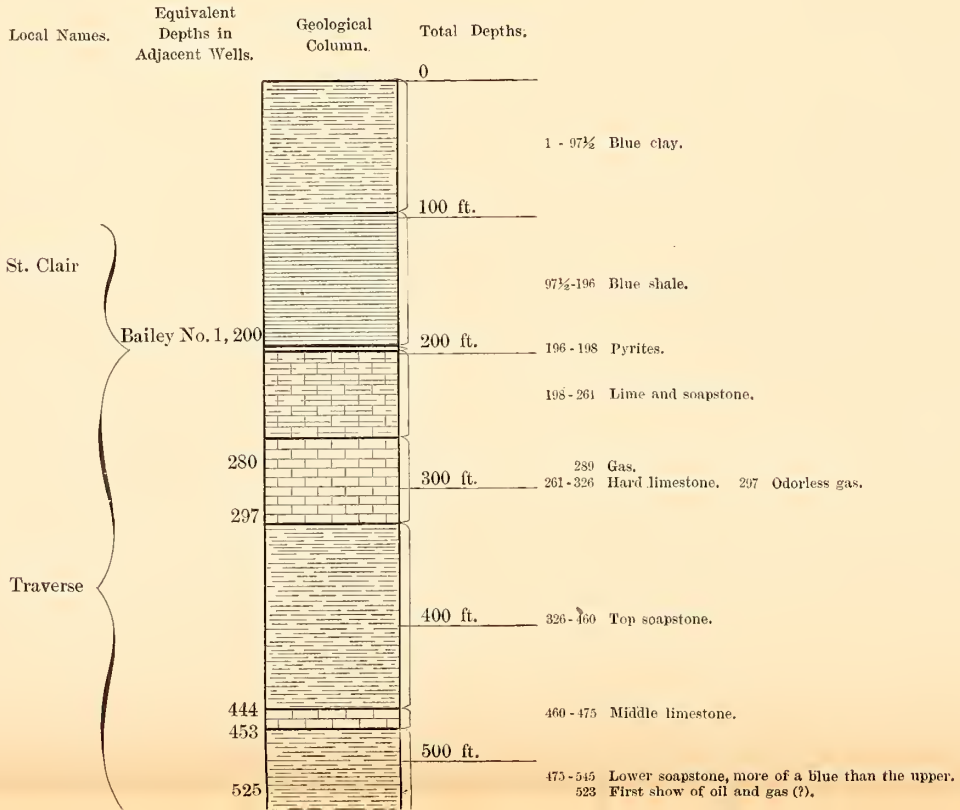
620 S. Hard grey limestone; scarcely any residue.
630 S. Hard grey limestone; very small residue.
640 S. Hard grey limestone; very small residue, fossiliferous.
} All effervesce briskly.

ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells, at Port Huron.
S. is placed after points from which samples are taken.

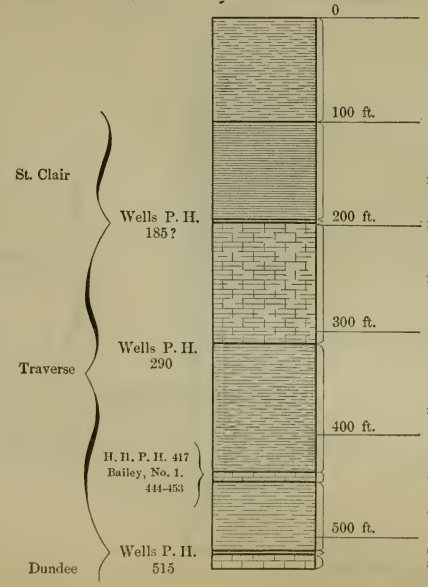
PORT HURON, No. 2.

C. A. Bailey's well, No. 2. Depth, 640 ft.
C. E. Wright.



PORT HURON, No. 3.

C. A. Bailey's well, No. 3. Depth 530 ft.
C. E. Wright. Commenced Aug. 1st, finished Aug. 15, 1886.

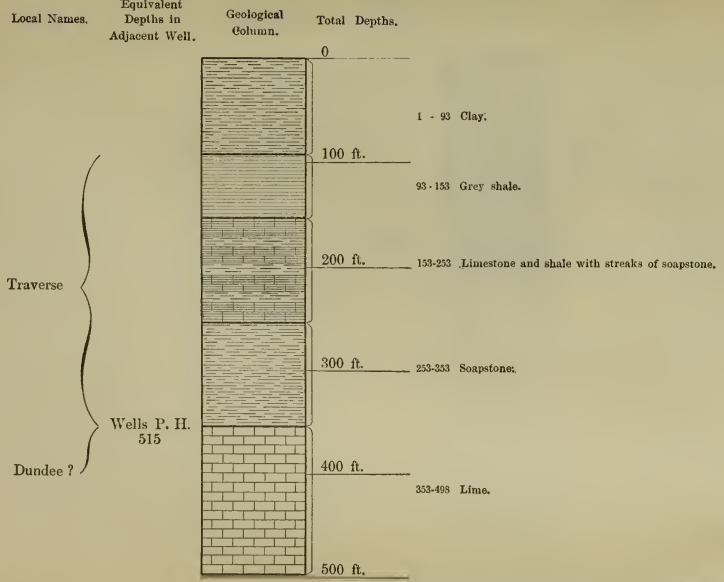


Driller's record.		Samples from a well, the location of which is not given.	
0-100	Blue clay.		
	Gas on surface.		
100-195	Black shale.	100-200	Black shale.
195-197	Iron pyrites.	200-204	Hard streak on top of top limestone.
197-312	Lime and soaprock mixed.	204-329	Top limestone.
318	Odorless gas.		
312-438	Soapstone.	329-458	Upper soapstone.
438-447	Middle lime.	458-464	3 to 9 ft. of middle limestone.
447-512	Lower soapstone.	464-520	60-65 ft. of lower soapstone.
512-514	Hard streak under which comes the gas.	520	Oil rock.
512-530	Lower lime. Show of oil at 521; 1 qt. in 8 days.	520-535	Lower limestone.

ABBREVIATIONS.

H. H. stands for Howard's well. The other references are to the boring of F. L. Well's.

Chadwick well; E. and W. line of S. 15, T. 6, R. 16. (Has a burner, i. e., is a gas well.) Depth 498 ft.
C. E. Wright. This record does not harmonize well with others.

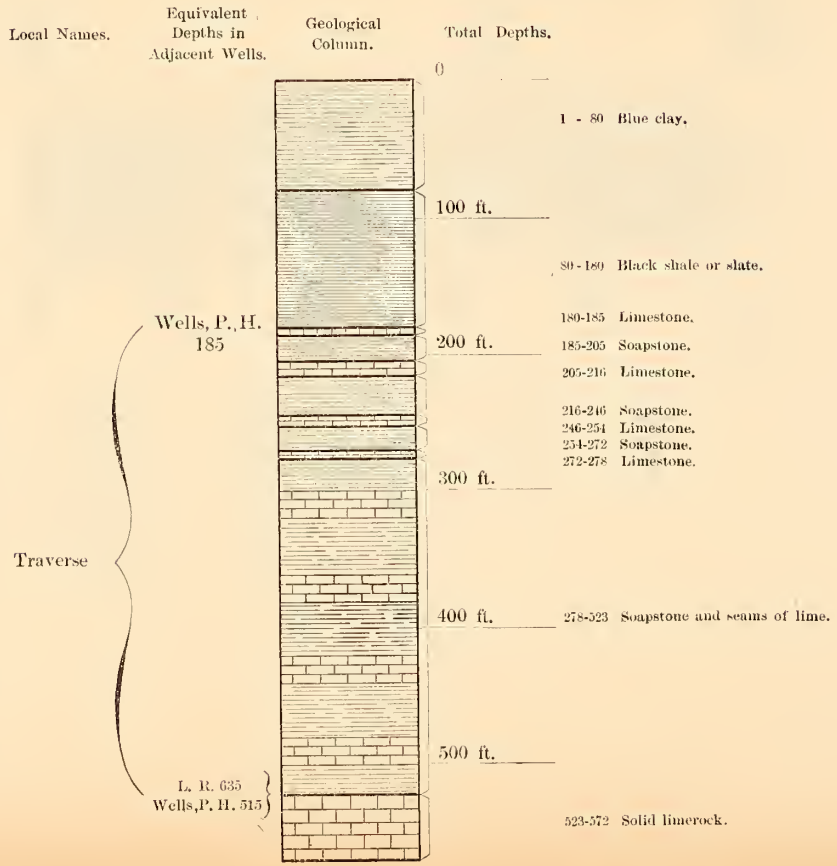


The reference to 515′ in the boring of F. L. Wells is dubious.

PORT HURON, No. 5.

Plate LII.

T. J. Gordon. Depth 572 ft.
C. E. Wright, and samples labelled Gordon and Hall.



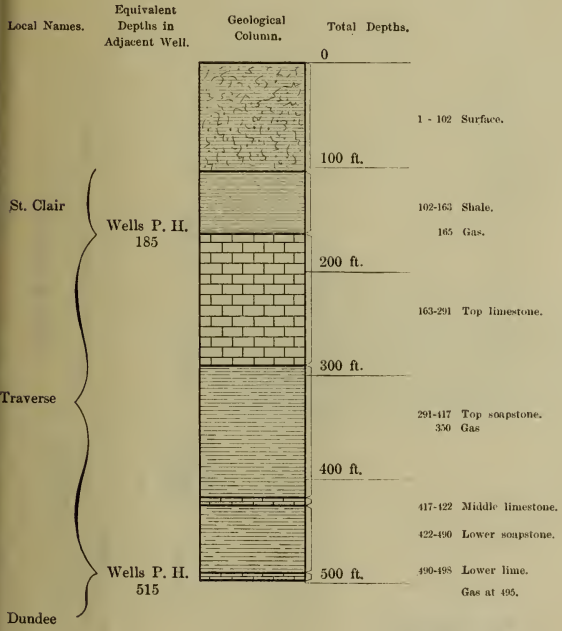
ABBREVIATIONS.

L. R. refers to Lester & Roberts' well, at Marine City.
Wells P. H. refers to well of F. L. Wells at Port Huron.

PORT HURON, No. 6.

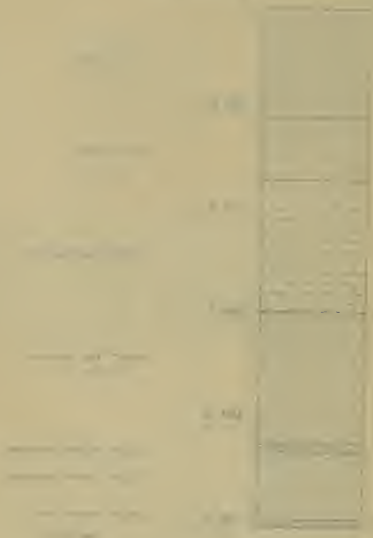
Plate LIII.

Henry Howard well. Depth 498 ft.
C. E. Wright.



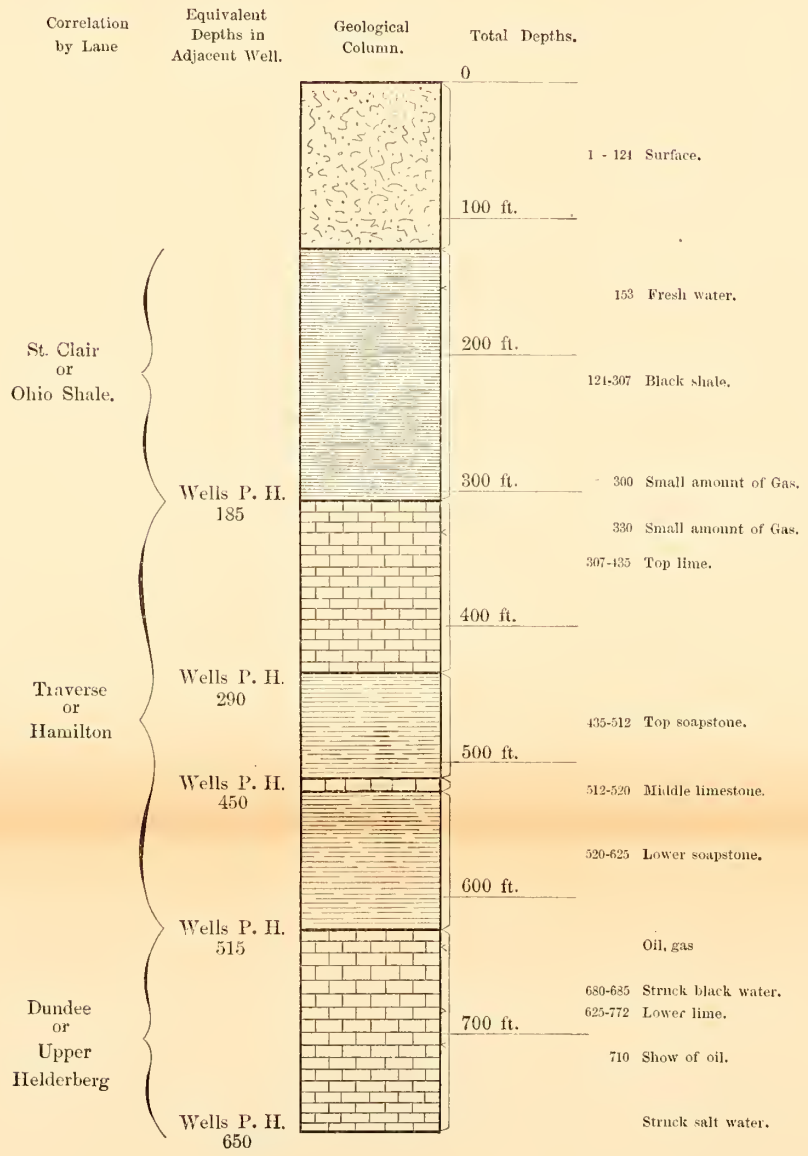
ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells, at Port Huron.



PORT HURON, No. 7.

St. Clair Co., Alt. 623 ft.
Junction well, ½ mile south, 1½ miles west of Bailey Wells. Depth, 772 ft.
C. E. Wright.

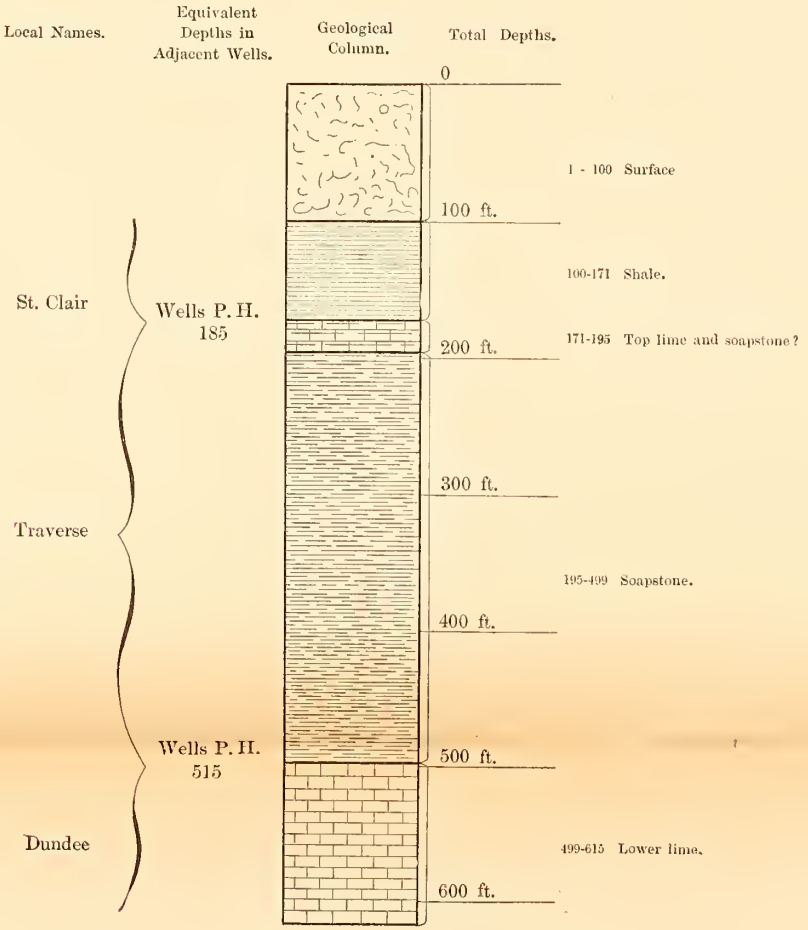


ABBREVIATIONS.

Wells P. H. refers to the borings of F. L. Wells at Port Huron.

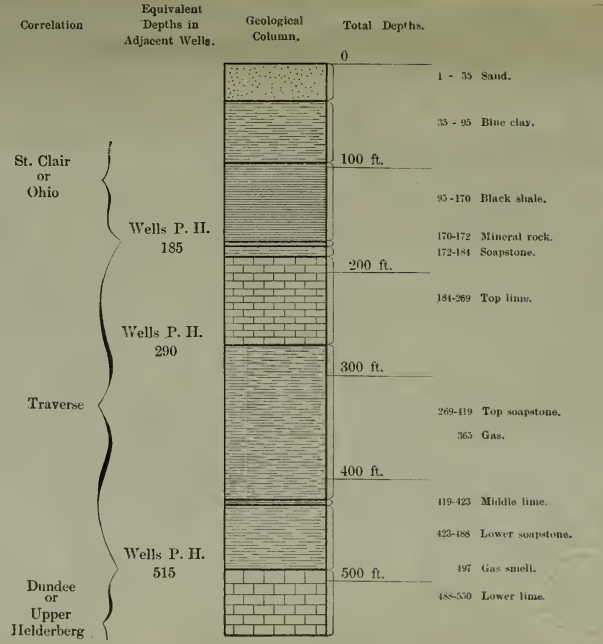
McMorran, No. 1. Depth 615 ft.
C. E. Wright. Analysis of the gas.

$C H_4$	77.70
$C_2 H_6$	7.83
H	4.9
Benzine	3.75
$C O_2$	.77
Illuminating Hydrocarbon	4.22
Oxygen	1.54
Nitrogen	4.00



ABBREVIATIONS.

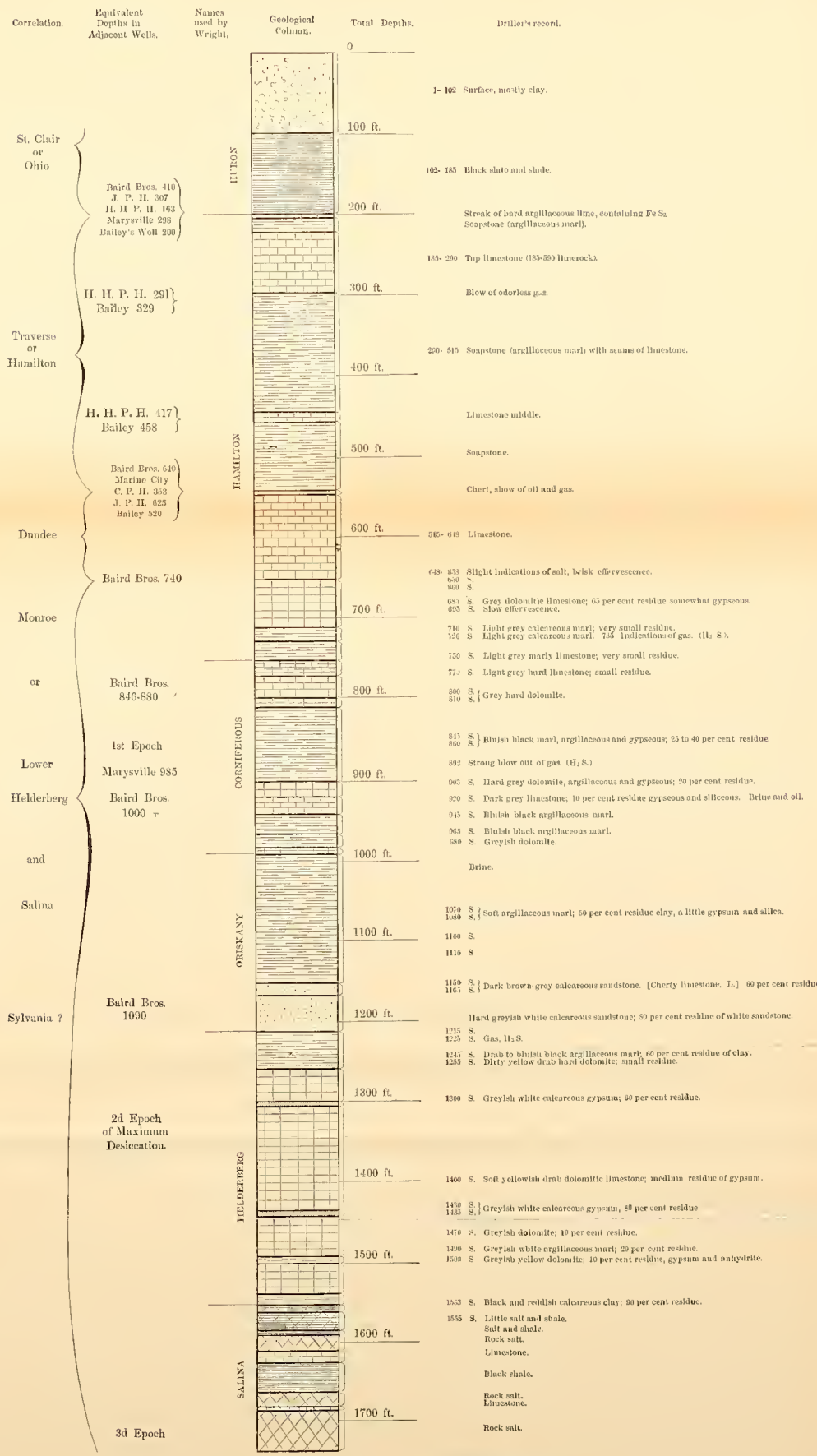
Wells P. H. refers to the boring of F. L. Wells at Port Huron.



ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells at Port Huron.

St. Clair Co., Alt. 633 ft. to 589 ft.
F. L. Wells; begun Aug. 1st, 1886. Depth 1685 ft. +
Port Huron Daily Times, May 28th, 1887. C. E. Wright; with samples.

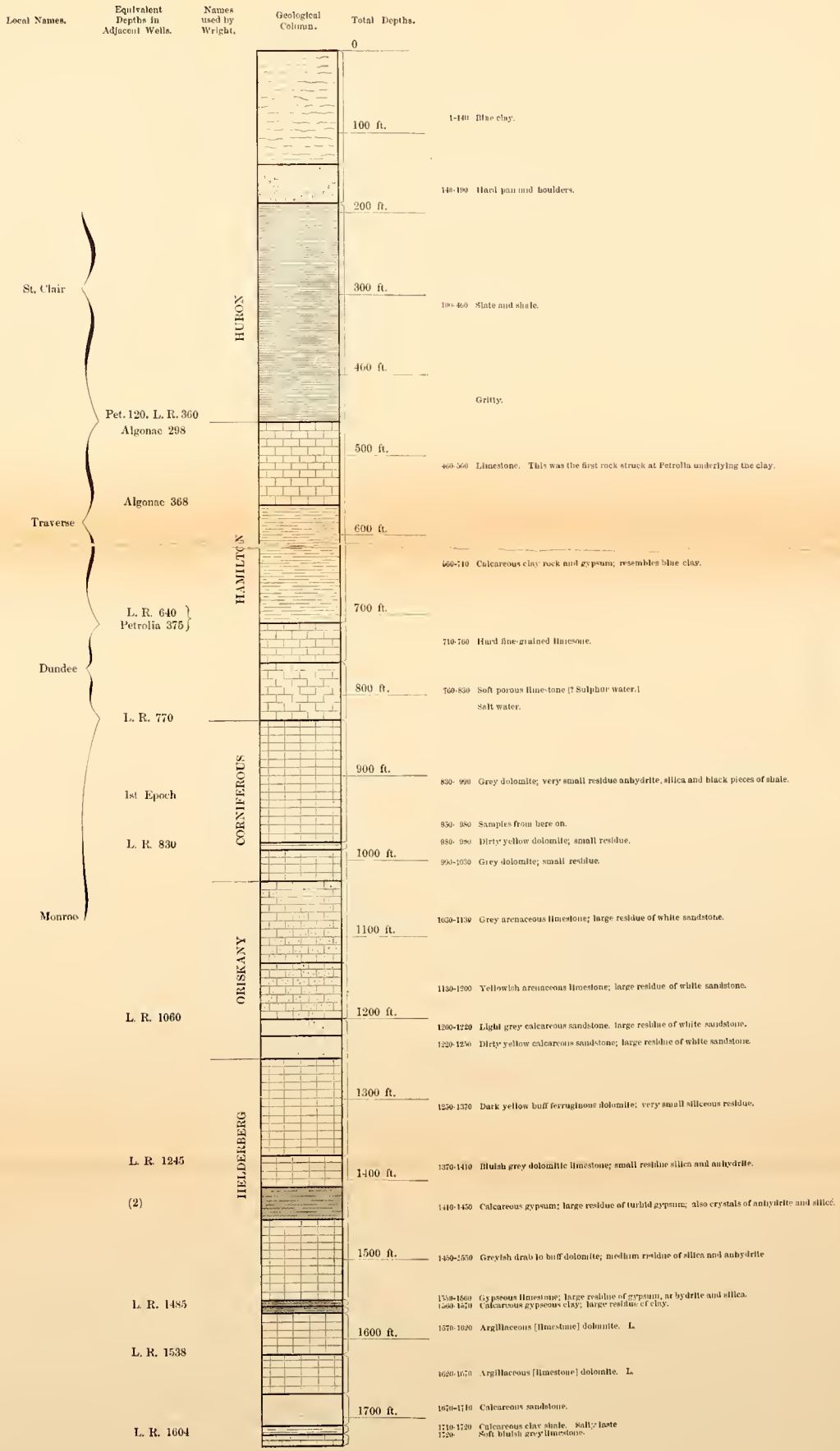


ABBREVIATIONS.

Fe S2 = Iron Pyrites.
H2 S = Sulphide Hydrogen.
H. H. P. H. refers to Howard's well at Port Huron.
C. P. H. refers to Chadwick's well at Port Huron.
J. P. H. refers to Junction well at Port Huron.
Baird Bros. refers to their well at Marine City.
S. is placed after points from which samples are taken.

PORT LAMBTON, CANADA.

Alt. about 600 ft.
Salt well. Depth 1720 ft. 5 miles northeast of Algonac.
C. E. Wright, samples with the State Survey.



ABBREVIATIONS.

L. R. refers to Lester and Robert's well at Marine City.
Pet. refers to the well at Petrolia.

ROMEO.

Macomb Co.
Boring sunk for village of Romeo; altitude of mouth about 75 ft. above R. R. station.
Contractor, Mat. Porter. Authority, Fred. E. Hipp.
Water rose about 1000 ft. (? to Lake Level.)

ROYAL OAK, No. 2.

Mfg. and Gas. Co. Depth 2502 ft.
Hugh Munro, Driller.

Local Names.	Equivalent Depths in Adjacent Wells.	Names used by Wright.	Geological Column.	Total Depths.	
				0	
					1- 40 Clay.
					40- 45 Gravel.
					45- 10 Clay.
				100 ft.	
					50- 101 Quicksand and gravel.
St. Clair		HURON		200 ft.	
					161- 505 Black shale.
	Pontiac 965			300 ft.	
					505- 590 Limestone.
Traverse	Pontiac 1065	HAMILTON		400 ft.	
					590- 550 Dearn shale.
	Wells P. H. 515			500 ft.	
	Newburg Ohio 1350				510 Salt water.
					585 Salt water.
Dundee and Monroe		CORNIFEROUS		600 ft.	
					526- 856 Limestone, containing salt water. [As this record does not distinguish dolomitic and limestone, we cannot fix the boundary between the Monroe and Dundee limestones.]
				700 ft.	
					750 Salt water.
				800 ft.	
					856 Salt water.
				900 ft.	
					856- 990 White sand.
					856-1105 Very soft white sandstone.
P. L. 1025-1145 Newburg, Ohio 1700		ORISKANY		1000 ft.	
					990-1105 Limestone. Struck white sand 990-1005, very soft. (May this be only drift?) L.
				1100 ft.	
Wyandotte 360 Wells P. H. 1150					1095-1125 Very gritty hard limestone.
					1125-1140 Dark sandrock, grey.
Wells P. H. 1215					1140-1155 Blue hard gritty limestone.
				1200 ft.	1155-1215 Very soft light-colored lime.
					1215-1261 A little sheet, same kind of rock.
Wyandotte 530-690		DELAWARE		1300 ft.	
					1260-1305 Hard close bluish limerock.
				1400 ft	Dec 3rd, 1886.
					1405-1410 Hard grey sandrock.
					1410-1450 Hard limerock.
					1450-1465 Hard gritty limerock.
				1500 ft.	
					1465-1545 Rotten lime or shale. (The "shale" and "slate" are probably largely anhydrite, or at times dolomitic marl.)
Wyandotte 780 Newburg 1900 Wells P. H. 1555					
(1)				1600 ft.	1515-1610 Solid rock salt.
					1610-1650 Hard shale.
(2)					1650-1695 Nice quality of salt.
				1700 ft.	
					1695-1735 Shale, rotten lime or shale, marly.
(3)					1735-1792 Salt.
				1800 ft.	1792-1810 Hard blue lime.
					1810-1880 Shale.
(4)					1850-1901 Salt.
				1900 ft.	1901-1910 Salt sour lime.
					1910-2065 Hard lime.
				2000 ft.	
(5)					2015-2050 Salt.
					2050-2115 Shale.
				2100 ft.	
(6)		SALINA			2115-2150 Salt.
					2150-2165 Shale.
(7)					2165-2185 Salt.
				2200 ft.	2185-2200 Shale.
(8)					2200-2300 Salt.
				2300 ft.	
					2300-2315 Shale.
(9)					
				2400 ft.	2315-2415 Salt.
					2415-2502 Hard blue lime.
				2500 ft.	

ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells at Port Huron.
P. L. refers to the well at Port Lambton.

St. Clair Co., Mich. (?) Alt. 600 ft.
St. Clair Salt Works, sunk by Matt. Porter for J. S. Thompson. Depth 1682 ft.
C. E. Wright.

Local Names.	Equivalent Depths in Adjacent Wells.	Geological Column.	Total Depths.	
			0	
				1 - 105 Surface.
			100 ft.	105- 106 Gravel.
			200 ft.	215 Gas into the black slate.
St. Clair				
			300 ft.	
			400 ft.	
			500 ft.	
Traverse			600 ft.	
			700 ft.	
			800 ft.	
	Courtwright 836 L. R. 635 ? Wells P. H. 515 or Wells P. H. 648 to " " 810			Mineral water; also gas.
			900 ft.	
			1000 ft.	
			1100 ft.	
			1200 ft.	
			1300 ft.	
			1400 ft.	
			1500 ft.	
			1600 ft.	
2d Epoch	Courtwright 1650 Marine City 1590			1650-1656 Salt. Hard limestone.

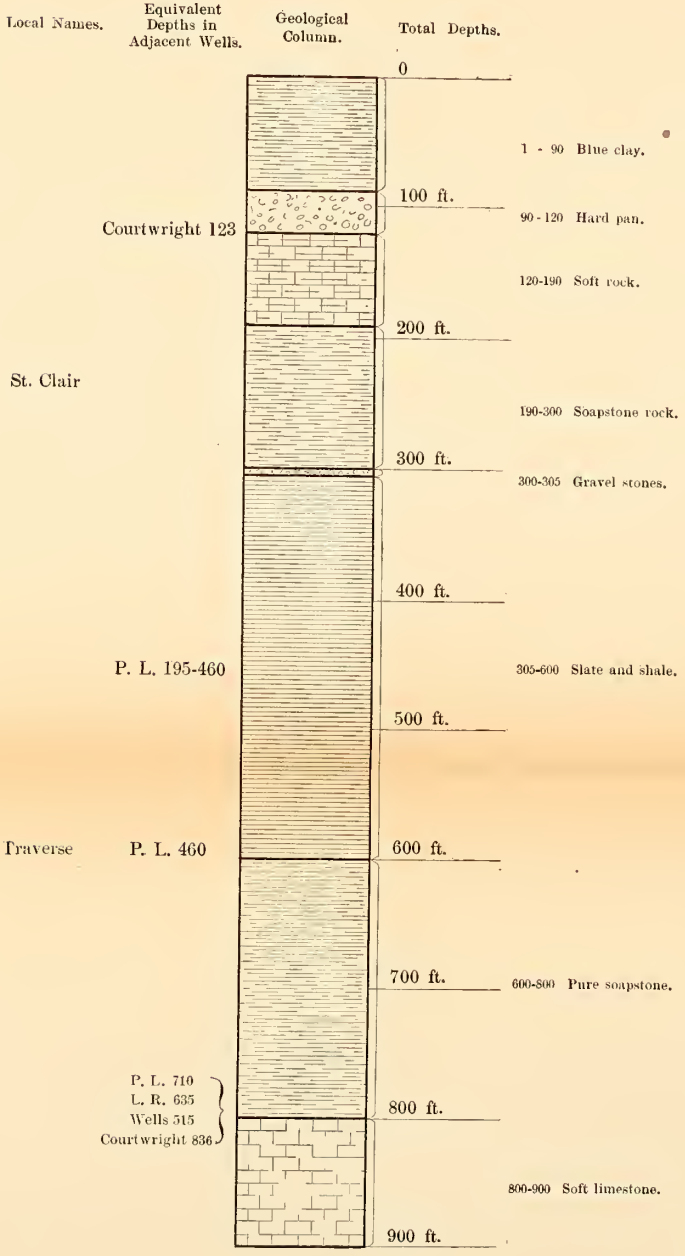
ABBREVIATIONS.

Wells P. H. refers to the boring of F. L. Wells at Port Huron.

L. R. refers to the well of Lester & Roberts, Marine City.

Oakland Well. Depth 900 ft.

Mark Hopkins. These records cannot be correlated; if the break at 800 ft. marks the bottom of the Traverse group, this well indicates a flexure and bottom of a synclinal, but the salt is at about the same depth as at Marine City in No. 1.



ABBREVIATIONS.

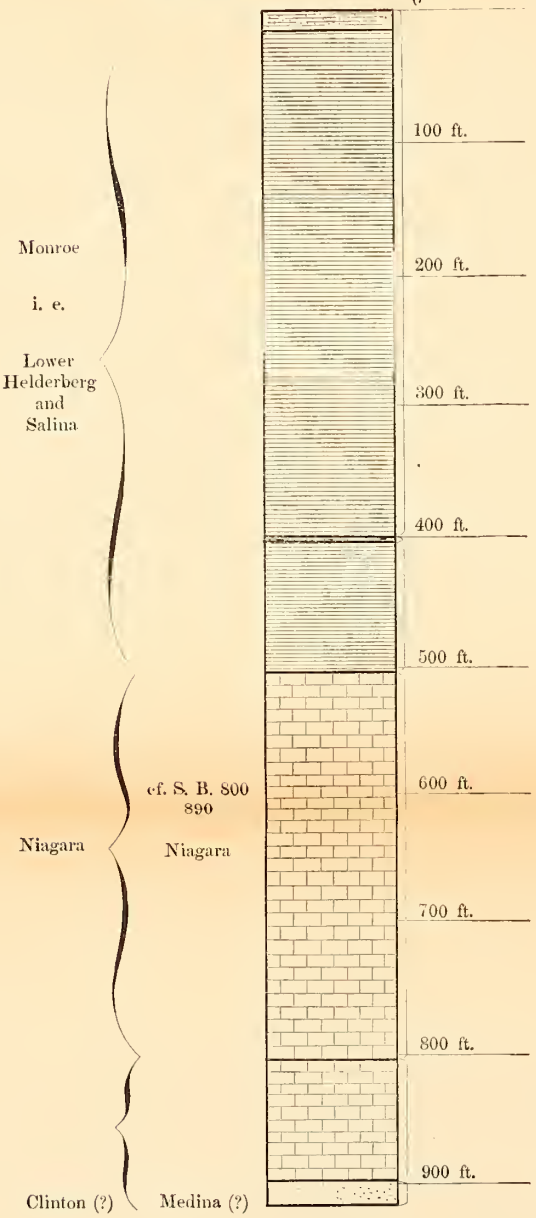
P. L. refers to the well at Port Lambton.

L. R. refers to the well of Lester & Roberts, Marine City.

Wells, refers to the well of F. L. Wells at Port Huron.

ST. IGNACE.

Mackinac Co. Alt. about 600 ft.
Mackinac Lumber Co. O. W. Johnson, Racine, Wis. Depth 919 ft.
W. A. Burt. See also Marquette Mining Journal, Sept. 26th, 1887. Henry Erratta, Contractor.



1- 15 Sawdust and clay.

15-400 Red and blue slates, principally red. Strongly impregnated. Salt water with a bitter taste.

400-404 Red marl and a vein of salt.

404-504 Blue slate.

504-804 S. Limestone. [Contains a little dolomite and gypsum.] Very light buff. Dolomite with slow effervescence.

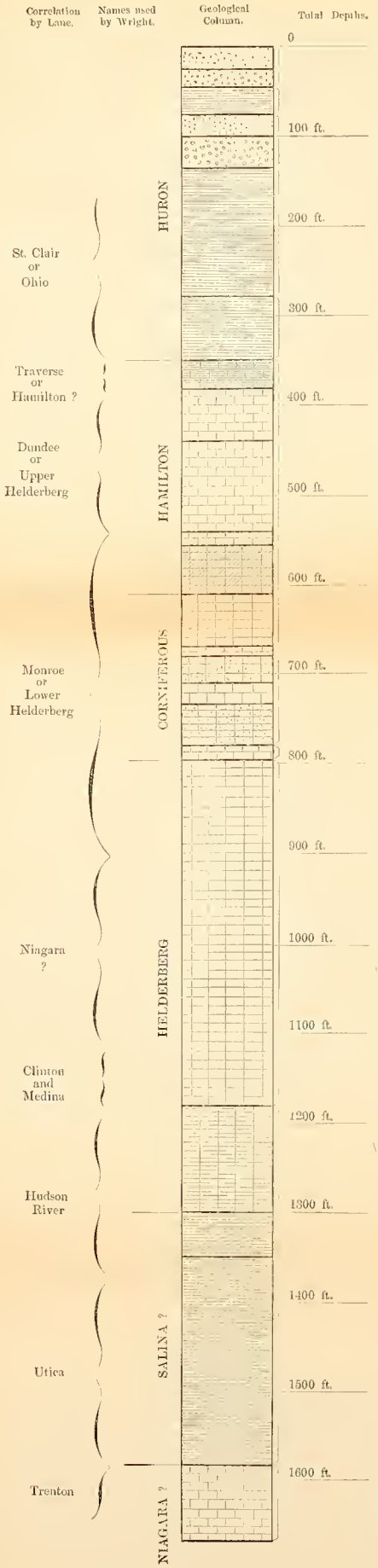
804-899 S. Driller's name, sandstone; with a strong smell, oily.
White limestone; contains a little gypsum, 2 per cent

899-919 S. Calcareous sandstone (grey); 90 per cent chert, etc.; rusty.
Some gas.

ABBREVIATIONS.

S. B. refers to well at South Bend, Indiana.
S. Sample.

St. Joseph Co., Indiana. Alt. 725 ft.
Oliver Chilled Plow Works. Depth, 1676 ft.
D. S. Hoffman; C. E. Wright; samples.



1- 25 Sand.
25- 45 Gravel
45- 75 Clay.
75- 100 Sand.
100- 137 Gravel

"Blue shale."
137- 280 Calcareous clay shale; dark drab; slow effervescence; 90 per cent residue.

Strong smell of oil from 200 ft. to 350 ft.

280 Gas.
Strong smell of crude petroleum from 200 ft. to 350 ft.

281- 350 Bituminous argillaceous shale; dark brown; no effervescence.
"Red shale."

350 Argillaceous limestone; bluish drab; brisk ef., cold; 40 per cent residue of clay.

365
381
385
387 Salt water.

420
425
435
440
450
455
460
470
475 Limestone; light drab; very brisk ef.; 2 to 3 per cent residue of silica, clay and coal.

540 Dolomitic limestone; drab; slow ef. cold acid; 4 per cent residue of clay, silica and some organic matter.

555 } Gypsum and dolomite; drab and white mixed; 15 per cent residue of gypsum.
590
660

610 Salt water.
635 } Dolomite; light drab, f. g., m. g.; 5 to 10 per cent res. of fragments of shale, rounded grains of glassy sand and an occasional
653 } one of liquid gypsum; also pyrites.
670

670 Salt water.
680 Dolomitic limestone; grey; f. g., slow ef.; 1 per cent res. of rounded grains of glassy sand and white silica.

710 Dolomite; light grey; m. g.; slow ef. cold acid; 6 per cent res. rounded glassy sand, blue sandstone and gypsum.
733 Dolomitic limestone; light grey; f. g.; brisk ef. in cold acid; 1 per cent res. of glassy sand and fragments of sandstone.
753 Dolomite; drab; slow ef., 12 per cent res. of hard light drab sandstone, reddish and dark quartz, and rounded grains of glassy sand.
780

796 Dolomitic limestone; light grey; fine grained; (moderate) ef. cold acid; 1 per cent residue of glassy sand and sandstone.

800 } Dolomitic limestone; bluish grey; f. g.; (moderate) ef. cold acid; 2 per cent res. glassy quartz, gypsum and reddish and dark
890 } grains of silica.
900
960 Dolomitic limestone; greyish white; m. g.; (moderate) ef. cold acid; 2 per cent res. rounded glassy sand, reddish and dark sand and a little sandstone.

950 { (Dolomitic limestone.) (Moderately brisk effervescence in cold acid.)

1000 Dolomite; greyish white; f. g.; slow ef. in cold acid; 1 per cent residue of fine silica.

"Limestone for 950 ft."

1100 Dolomite; greyish white; f. g.; slow ef. in cold acid; 2 per cent residue of gypsum and glassy grains of sand; also bluish grey sandstone.

1150 Dolomite; yellowish grey with dark ochreous specks; slow ef. in cold acid.
1180 Argillaceous dolomite; bluish drab and grey; slow ef. in cold acid; 20 per cent residue of dark clay, white quartz and pyrite.

1265 Argillaceous dolomite; bluish grey; slow effervescence; 20 per cent residue of clay.

1300

1350 Argillaceous shale; dark bluish drab; slow ef. cold acid; 95 per cent residue.

1400 Argillaceous shale; dark brown to black; very slow ef.; 98 per cent residue.

"Blue shale."

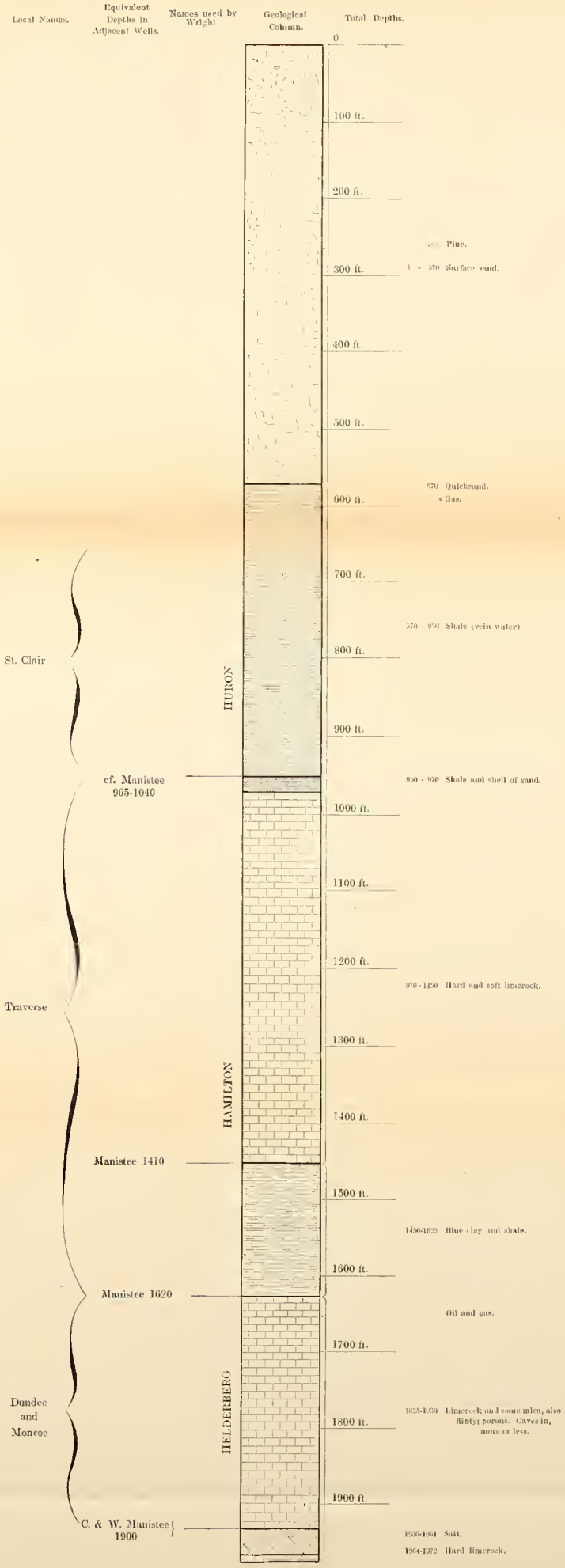
1500 Argillaceous shale; dark brown to black; very slow ef.; 98 per cent residue.

1585 } Dolomitic limestone; drab; med. brisk ef. in cold acid; 8 per cent residue clay shale.
1595 }
1600 }
1605 } Dolomitic limestone; drab; med. brisk ef. in cold acid; 3 per cent of clay, shale and silica.
1610 }
1620 }
1630
1640

1650 } Salt water. 1650 Dolomitic limestone; drab; med. brisk ef. in cold acid; 2 per cent. residue of clay, shale and silica.
1660 } 1660 Dolomitic limestone; drab; med. brisk ef. in cold acid; 1 per cent residue of clay, shale and silica.
1670 } 1670 Dolomitic limestone; drab; med. brisk ef. in cold acid; 5 per cent residue of clay, shale and silica.

ABBREVIATIONS.
M. g.=Medium grained.
F. g.=Fine-grained.
Ef.=Effervescence.
Res.=Residue.

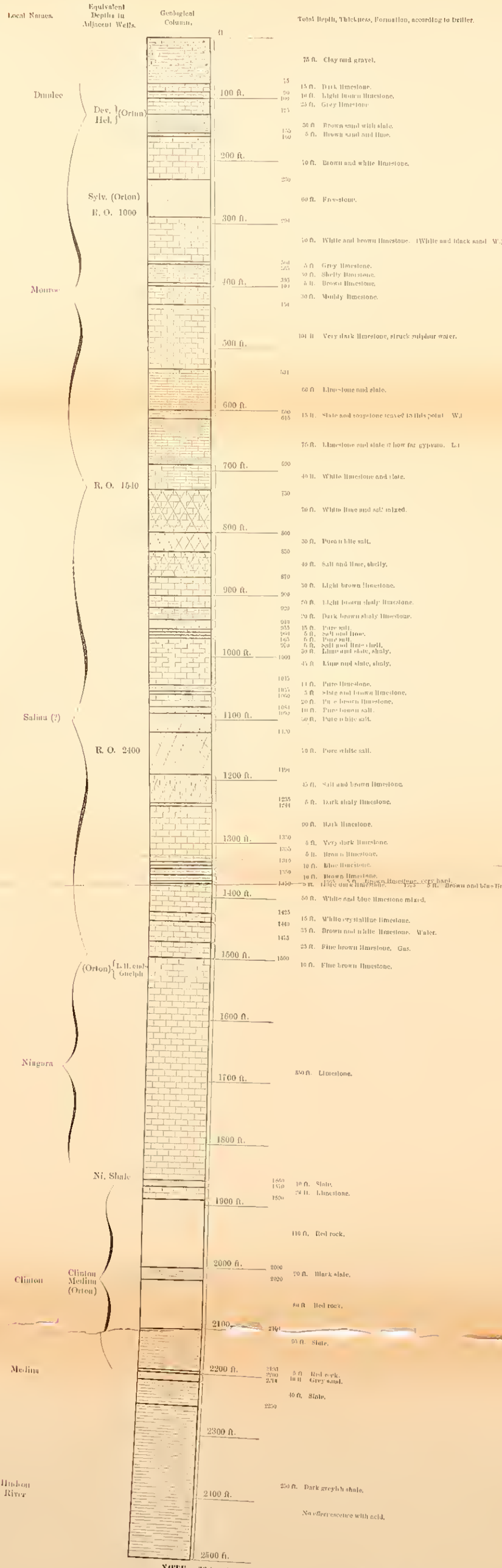
Manistee Co., Alt. 604 ft.
Stronach Lumber Co. Depth 1972 ft. at the head of the Lake.
C. E. Wright and Thomas Percy.



ABBREVIATIONS.

C. & W. refers to well of Caulfield & Wheeler, Manistee.

Wayne Co. Alt. 580 ft.
Lacey and Churchill, Contractors. Depth 2500 ft.
A record of the first 1510 ft. was left by Mr. Wright. The complete record came from Dr. Alex. Winchell by Prof. Edward Orton. In both cases it is only the driller's record. Correlation by Lane.



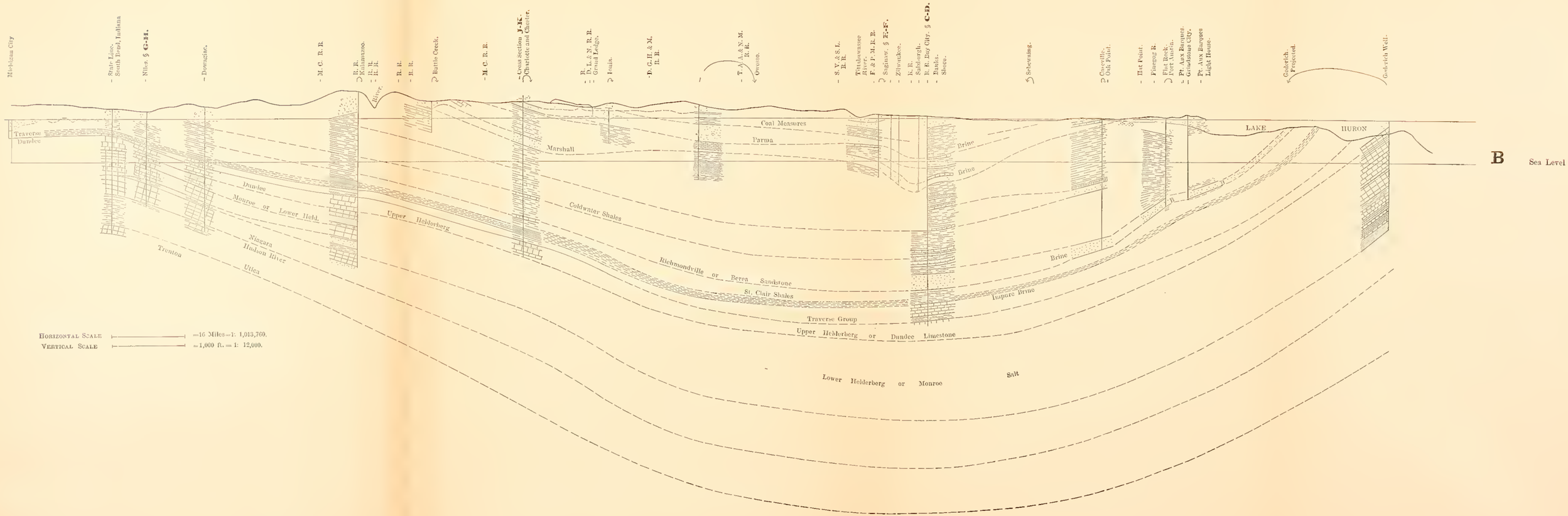
NOTE.—This driller's record bears internal evidence of not being scientifically very trustworthy. When Wright's record differs from that obtained through Prof. Orton it is added in parenthesis with a W.

ABBREVIATIONS.

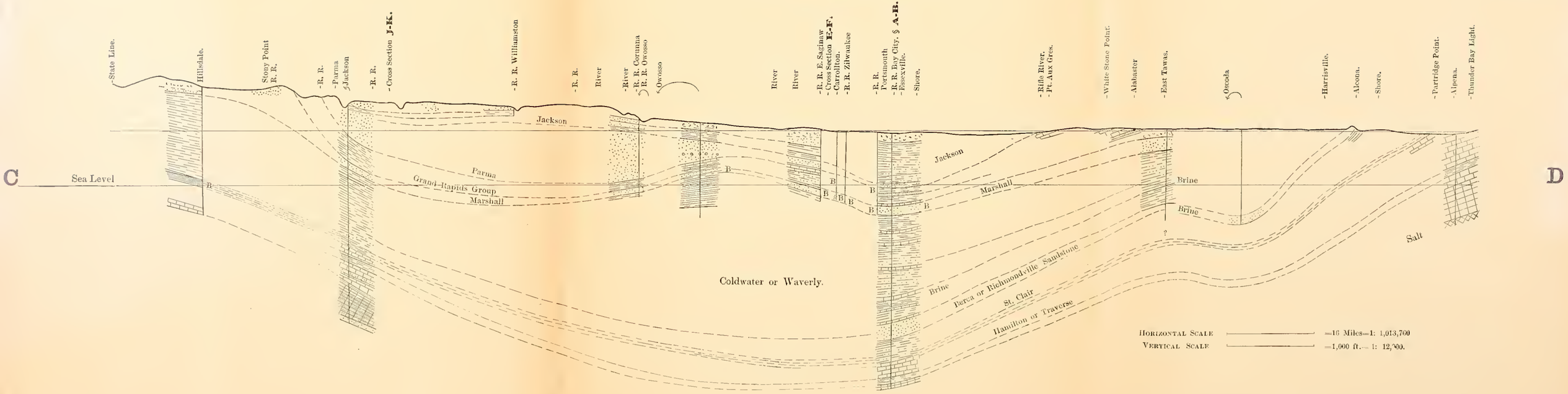
Dev.=Devonian.
Hel.=Helderberg.
Sylv. Sylvania.
R. O. refers to Royal Oak well.
L. H.=Lower Helderberg.
Ni.=Niagara.

GEOLOGICAL CROSS-SECTIONS OF LOWER MICHIGAN.

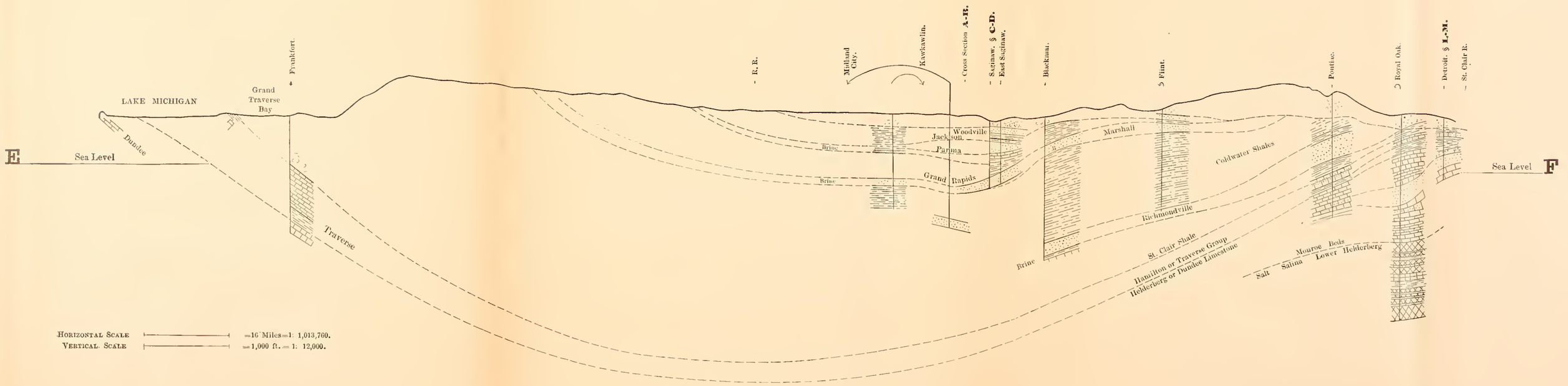
No. 1. NILES TO BAY CITY.



No. 2. HILLSDALE TO BAY CITY.



No. 3. DETROIT TO SAGINAW.



No. 4. NILES TO FRANKFORT.

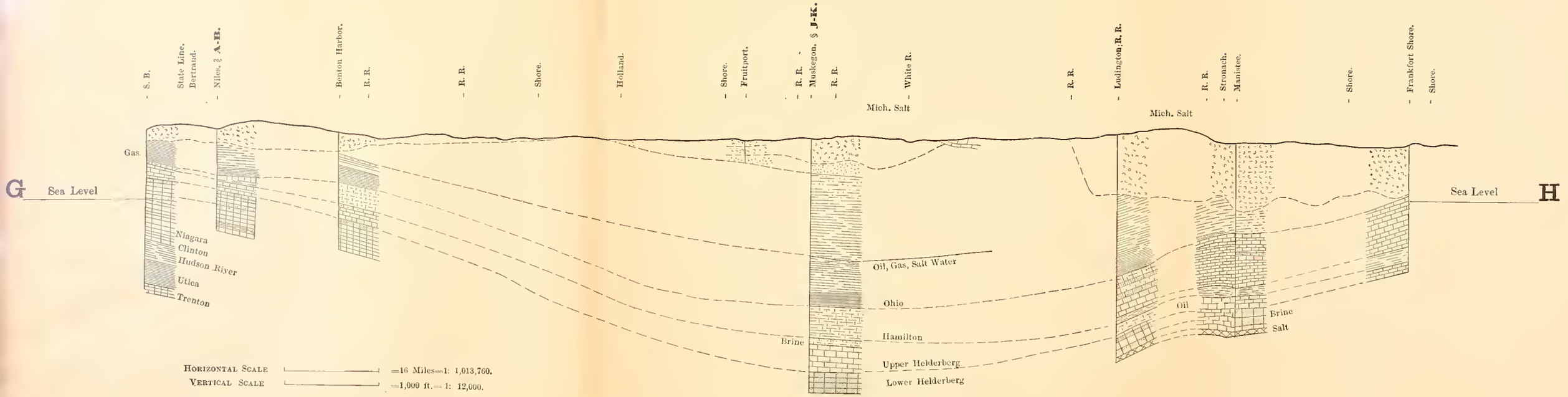
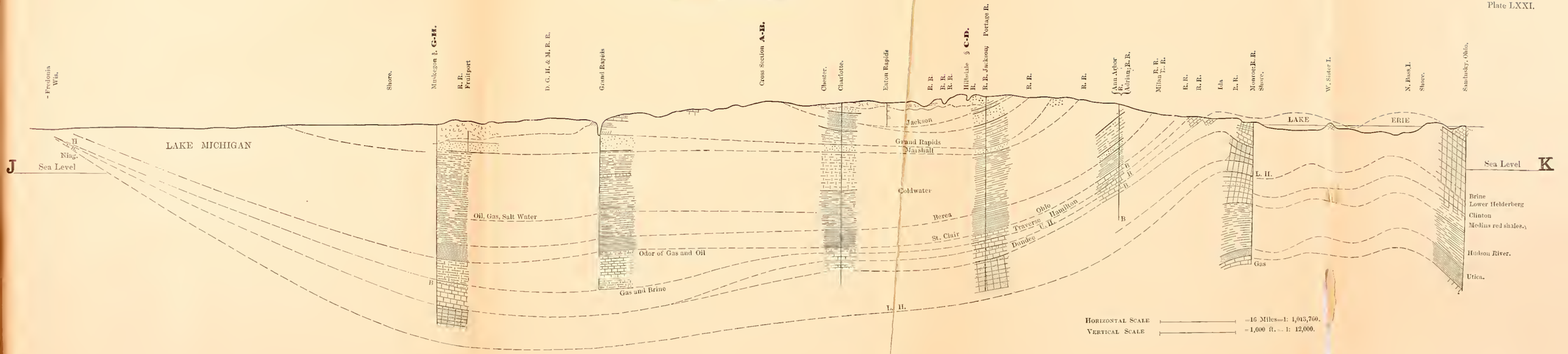


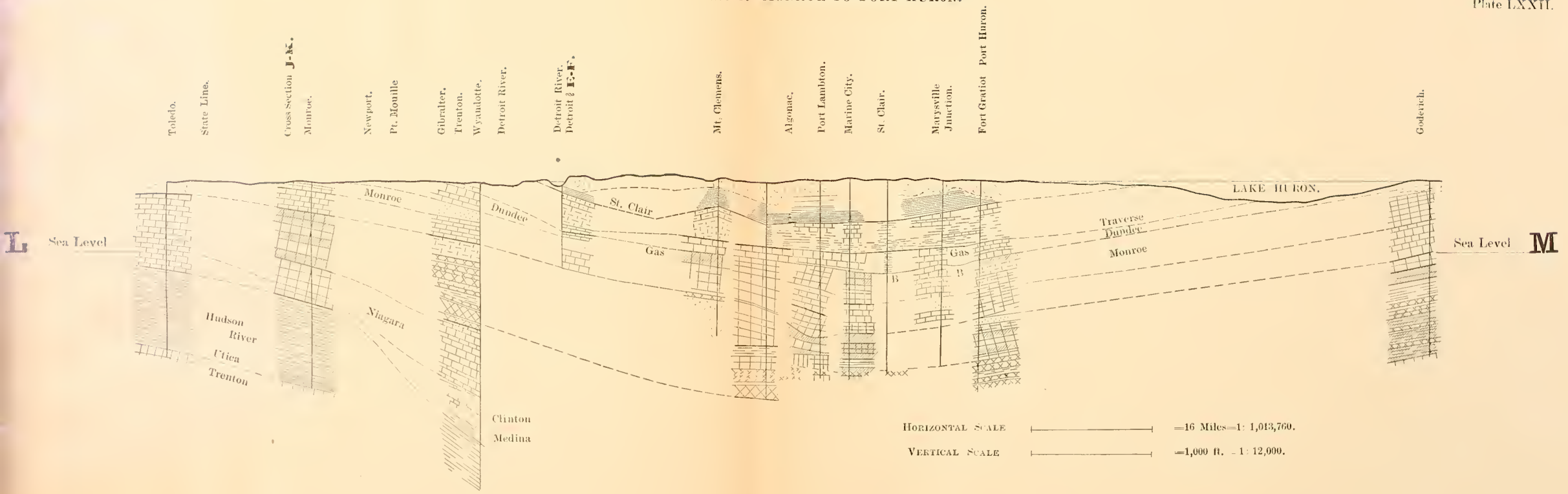
Plate LXXI.

No. 5. MUSKEGON TO CHARLOTTE.



No. 6. MONROE TO PORT HURON.

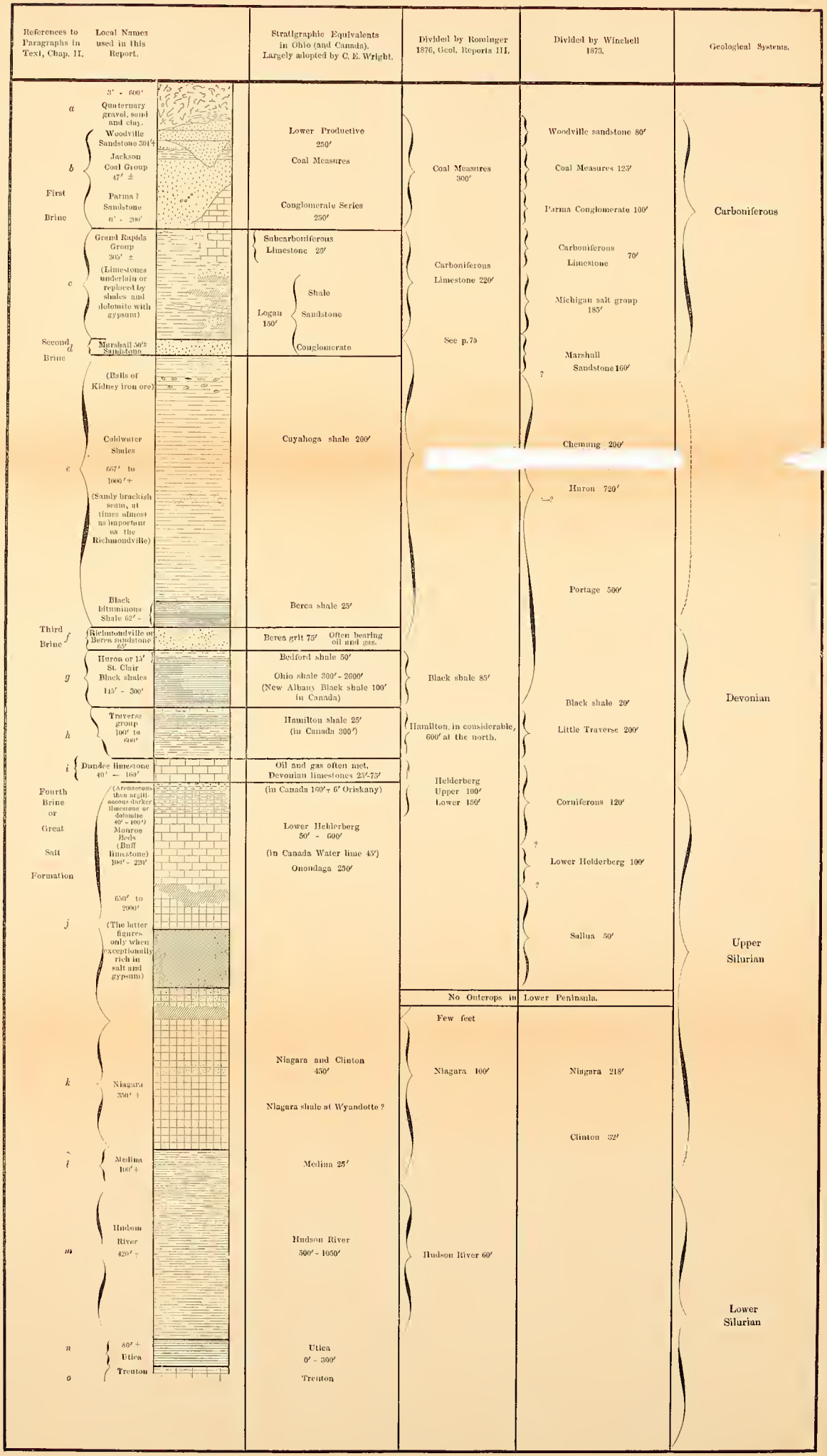
Plate LXXII.



GEOLOGICAL COLUMN for SOUTHERN MICHIGAN, based chiefly on deep borings

— at —

JACKSON AND MONROE.



SCALES
Statute Miles, 69.16 = 1 Degree.
Kilometres, 111.307 = 1 Degree.
LONGITUDE WEST FROM GREENWICH.
MACKINAC
CHIPPEWA
ST IGNACE
STRAITS OF MACKINAC
MANISTIQUE
ST JAMES
BEAVER ISLAND
CHEBOYGAN
EMMET
HARBOR SPRINGS
CHARLEVOIX
BOYNE
ANTRIM
GAYLORD
OTSEGO
MONTMORENCY
LELAND
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
BENZIE
GRAYLING
ROSCOMMON
WEXFORD
MISSAUKEE
LAKE CITY
CADILLAC
OGEMAW
W BRANCH
MANISTEE
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
LUDINGTON
HERSEY
BIG RAPIDS
OCEANA
MECOSTA
ISABELLA
MOUNT PLEASANT
MIDLAND
NEWAYGO
MONTCALM
STANTON
GRATIOT
SAGINAW
MUSKEGON
GRAND HAVEN
GRAND RAPIDS
OTTAWA
IONIA
CLINTON
SHIAWASSEE
CORUNNA
LANSING
HASTINGS
ALLEGAN
CHARLOTTE
INGHAM
LIVINGSTON
HOWELL
MICHIGAN
MERIDIAN

WELLESLEY COLLEGE LIBRARY
3 5002 03596 2773

Science qQE125.
A12 5
Upper Peninsula,
1881-1844